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# BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

(FOR ARTICLES ON THE GEOLOGY OF EAST ANGLIA)

No. 38 1988

CONTENTS INCLUDE:

Chalk of Norwich

Amphibians and Reptiles of the West Runton Freshwater Bed

BULLETIN of the GEOLOGICAL SOCIETY OF NORFOLK

No. 38 October 1988

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## EDITORIAL

The long gestation period for Bulletin No.38 has been in part due to the complexities of preparing Chris Wood's comprehensive and detailed account of the Chalk of Norwich for publication. Originally written as a draft chapter on the Chalk for a traditional Memoir to accompany the 1:50,000 Geological Map of Norwich (Sheet 161, 1975), it was all but totally abandoned when it was decided not to produce a full-scale Memoir. Through the gentle insistence of Norman Peake that it was too valuable to be lost, and through the considerable help of Chris Wood himself and of Reg Thurrell at B.G.S. we have managed to rescue and up-date it for publication. In a sense it compensates for the lack of a chapter on the Chalk in Bulletin No.34 "East Anglian Geology" (1984), and is the first revision of the stratigraphy of the local Chalk since the Society's publication "The Geology of Norfolk" (1961, 1970, 1979), which is now out of print. In spite of the heroic efforts of Chris Wood in bringing his manuscript up-to-date the whole operation would not have been possible without the generous provision of typing and drafting resources by the School of Environmental Sciences at U.E.A., and in particular the dedication of Mrs Barbara Slade, and latterly Mrs Frances Randell, in word processing successive versions of the paper. To all these we extend our very considerable thanks. The resultant paper deserves to be widely consulted.

## Editorial

All that remains to be said is that the present Bulletin is concluded by a short paper by Alan Holman, John Clayden and Tony Stuart on the herpetofauna (amphibians and reptiles) of the "Cromer Forest Bed".

Because of the delays over the setting up of Bulletin No.38 the promised Reprint of Bulletin Numbers 1 to 10 did not appear in 1987; it should now do so before the end of 1988.

## INSTRUCTIONS TO AUTHORS

Potential contributors should note that although we prefer manuscripts to be submitted in typewritten copy we will accept neatly handwritten material. It is most helpful if the style of the paper, in terms of capitalisation, underlining, punctuation, etc. is made to conform strictly to those normally used in the Bulletin. All measurements should be given in metric units. The reference list is the author's responsibility and should always be carefully checked.

Illustrations are important. They should be drawn with thin dense black ink lines. Thick lines, close stipple or patches of solid black should be avoided as these tend to spread in the printing process usually employed. Original illustrations should, before, reproduction, be not more than 175 mm by 225 mm. Full use should be made of the first (horizontal) dimension, which corresponds to the width of print on the page, but the second (vertical) dimension is an upper limit only. Half-tone (photographic) plates can also be accepted, provided the originals exhibit adequate contrast, and when their use is warranted by the subject matter.

Authors are reminded that the Bulletin of the Geological Society of Norfolk exists to publish research papers, notes or general articles relevant to the geology of East Anglia as a whole, and does not restrict consideration to articles covering Norfolk alone.

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Bull. geol. Soc. Norfolk, 38, 3-120 October 1988

# THE STRATIGRAPHY OF THE CHALK OF NORWICH

C.J. Wood*

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## 1. Introduction

This account, which was originally prepared in 1975 as a chapter for the Norwich Memoir and not as a scientific paper, largely follows memoir style and format of the British Geological Survey (BGS). The BGS is publishing the Norwich Memoir as an abbreviated account (Cox and others, _in press_), and has agreed that the material of the original chapter may be published in revised form in the Bulletin of the Geological Society of Norfolk. Since the time allocated to fieldwork was necessarily limited, this paper does not purport to be a definitive account of the Chalk of Norwich, but is essentially archival. It does, nevertheless, include much previously unpublished data, and records details of all the exposures available in the early 1970s, most of which have long since disappeared. The opportunity has been taken to revise and, in part, to rewrite the original account, particularly in the light of some of the preliminary results obtained by Mr. A. Pitchford (Liverpool University) in his current research on the palaeoecology of the Chalk of the few remaining exposures in the vicinity of Norwich.

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The Upper Campanian (Belemnitella mucronata Zone) Chalk succession long exploited in quarries and underground workings in and around the city of Norwich - the so-called 'Norwich Chalk' - was justly famed for the richness and superb preservation of its fossils. Although much of the Norwich Chalk must have been formerly well exposed in large working quarries, some remaining open until the middle of the present century, economic pressures have caused the majority of these pits to be abandoned, and today the number of exposures is extremely limited. This paper reviews the current state of knowledge of the Norwich Chalk, and touches briefly on the underlying Lower Campanian (local Zone of Gonioteuthis) and overlying Lower Maastrichtian (Belemnella lanceolata s.l. Zone) successions, which crop out to the west and east of the city respectively.

The study area constitutes the eastern half of the area covered by the BGS 1: 50 000 Geological Sheet 161 (Norwich), with a small overlap on to the Great Yarmouth (162) Sheet. It is bounded to the west by Attlebridge and Ringland, to the north by Taverham and Drayton, to the south by Tharston, and stretches east as far as Bramerton, taking in the whole of the city. The Alderford Common pit just to the north of Attlebridge, and localities in the valley of the River Bure such as Frettenham and the abandoned workings at 'Little Switzerland' near Wroxham, are excluded from consideration. The majority of localities lie within the 100 km square TG, and National Grid References for these are given in square brackets without the TG prefix. For those few localities in the 100 km square TM the TM prefix is included in the grid reference.

Over most of the area, the Chalk is concealed beneath a thick cover of marine Pleistocene, Glacial and Recent deposits, and outcrops are confined to the sides and bottoms of the valleys of the rivers

Wensum, Yare and Tas. The Chalk dips to the east at a low angle, so that progressively younger beds appear in this direction beneath the Pleistocene cover. There is much evidence of glacial disturbance of the Chalk, and it is probable that some apparently in situ exposures represent 'rafts' partly or wholly enclosed within till. There is consequently no certainty that any given exposure will be at the stratigraphical level predicted from its geographical position.

The Chalk of the area is covered by two late nineteenth century Geological Survey memoirs. The East Dereham Memoir (Blake 1888) provided details of the Lower Campanian localities around Marlingford, Ringland and Attlebridge, while the classic 'Norwich Chalk' was described in the first edition of the Norwich Memoir (Woodward 1882). More recently, the stratigraphy and palaeontology of the Chalk of Norfolk in general has been ably reviewed by Peake and Hancock (1961; 1970), and much of this information is directly relevant to the Norwich area.

In connection with the resurvey of the Norwich Sheet by BGS during 1965-1969 all the available exposures were examined, even where overgrown and/or obscured by talus, and this led to the rediscovery of a number of former pits whose location had been lost sight of, including some of considerable biostratigraphical importance. Macrofossil collections made from each locality by the author and Mr. A.A. Morter are registered under the symbol CJW and housed in the BGS Biostratigraphy Research Group collections in the National Geosciences Data Centre [NGDC] at BGS, Keyworth. The study of these collections was supplemented by examination of material collected in connection with the 19th century surveys, as well as fossils collected in the first half of this century by Dr. A.W. Rowe and Mr. R.M. Brydone and, in recent years, by Dr. J. Goff, Mr. P. Hammond, Dr. M.R.

Leeder and Mr. N.B. Peake. The Rowe collection is preserved in the British Museum (Natural History) [BMNH], and the bulk of the Brydone (Norwich) collection is in Norwich Castle Museum [NCM], with additional material in BGS. The Goff and Leeder collections are in NCM, and the Hammond collection - which includes a considerable amount of material from outside the sheet - is in the Sedgwick Museum, Cambridge [SM]. Rowe's unpublished field notebooks for Norfolk dating from 1908-11 [Palaeontology Library, BMNH] and MS notes associated with his fossils have proved to be an invaluable source of information on the quarries then in work and on all the smaller exposures. Extensive verbatim quotations from this MS material are given where appropriate throughout this paper, with the author's comments and explanatory glosses in square brackets. In addition, Dr. Leeder has kindly made available his MS notes on Norwich pits made in the 1960s, which include data on some key temporary exposures. Data on temporary sections at Bowthorpe and Cringleford have been provided by Mr. N.B. Peake, and on the sections at Eaton Limeworks and Keswick by Mr. A. Pitchford.

Throughout the paper, sections are described under their most commonly used name together with the National Grid Reference when this is known. The majority of sections can be found in Mr. N.B. Peake's MS list of fossiliferous Chalk exposures in Norfolk (1960), copies of which have been deposited in NCM, BGS, BMNH and SM. The first 186 of the 340 localities on this list are the pits numbered by Rowe in his field notebooks; the remainder were given numbers by Mr. Peake. Rowe/Peake numbers have been quoted where appropriate, as have MS locality numbers used by John Rhodes of the Geological Survey in 1884 for the pits in the western part of the area. Details of sections measured by the author and not published here can be consulted in his field notebooks, which are held in the BGS Biostratigraphy Research Group archives at Keyworth.

## 2. Stratigraphy

The Chalk of the Norwich area can be conveniently considered under the following heads, in ascending stratigraphical order:

(1) Zone of Gonioteuthis: (Lower Campanian Substage)

(2) Belemnitella mucronata Zone sensu lato: (Upper Campanian Substage)

(3) Belemnella lanceolata Zone (Lower Maastrichtian Substage).

The Zone of Gonioteuthis is today very poorly exposed. Exposures in the Belemnitella mucronata Zone (the classic 'Norwich Chalk') are more extensive. The Maastrichtian has been recognised only comparatively recently in the banks and bed of the River Yare near Bramerton, on the eastern margin of the study area.

### A. The Zone of Gonioteuthis:

This zone was originally named by Brydone (1931) the 'Zone of granulated Actinocamax' [i.e. Gonioteuthis], and corresponds to the combined Offaster pilula and Gonioteuthis quadrata zones of the standard southern England zonal scheme. It was introduced as a local zone in Norfolk (Peake and Hancock 1961) since it appeared at the time that the two standard zones were not readily distinguishable there on palaeontological evidence. It is now known, however, (Peake and Hancock 1970, p.339C) that this is not the case, but nevertheless poor exposure has limited precise biostratigraphical work, and it is still convenient in Norfolk to refer the beds between the top of the Marsupites Zone and the base of the Belemnitella mucronata Zone to an undivided Zone of Gonioteuthis.

With one exception, Carleton Forehoe (see p.12), which is believed to lie in the Offaster pilula Zone, all the Zone of Gonioteuthis localities discussed in this paper belong to the higher part of the Gonioteuthis quadrata Zone. This latter zone is poorly exposed in Norfolk, but even in southern England, where it is well exposed in sea-cliff and quarry sections, knowledge of the biostratigraphy remains unsatisfactory. For this reason, correlation between the isolated Norfolk exposures and the quadrata Zone succession in southern England cannot be given at present. A useful key to horizon within the Zone of Gonioteuthis in Norfolk is provided by a morphometric analysis of changes in Gonioteuthis, using the techniques perfected by Ernst (1964) in correlative successions in north-west Germany. Some promising preliminary work has been carried out by Mr. P. Hammond (Peake and Hancock 1970, p.339C), from which it appears that the alveolar angle of the guard decreases progressively upwards throughout the zone, this decrease reflecting a progressive deepening of the alveolus relative to the (preserved) length of the guard. However, a considerable number of specimens are required from any one horizon before a statistically valid assessment can be made, and it is rarely possible to collect more than a few specimens from most localities.

A useful account of the Zone of Gonioteuthis pits extant in the late 19th century in the area to the west of Norwich was published in the East Dereham Memoir (Blake 1888), which provides summarised lists of the fossils collected in 1884 by John Rhodes, the official Geological Survey collector. In the BGS fossil registers (held in the Biostratigraphy Research Group archives), each pit is recorded under a Rhodes locality number and, using 6" to the mile OS maps in conjunction with Old Series geological maps, it has proved possible to identify the position of the majority of these localities and to give them six-figure grid references. Several of the Rhodes localities were subsequently examined by Rowe and given locality numbers by him.

Some of the pits were also examined later by Brydone, but it is very difficult, and in some cases impossible, to identify which pits these were from the locality names given in his published papers. All the fossils collected by Rhodes (registered under the symbol R in the BGS Biostratigraphy Research Group collections at Keyworth) have been redetermined for this account, as has the small amount of relevant Rowe material that has been found in BMNH. Material collected by the author and Mr. A.A. Morter (registered in BGS under the symbol CJW) has confirmed the original zonal assignments in most cases, but it is far from clear to what extent all the localities can be considered as part of the *in situ* succession.

The Zone of *Gonioteuthis* pits are geographically distributed as follows:

(i) *Yare valley, from west to east*

**GREAT MELTON** [1320 0786]; Rhodes loc. 24.

Blake (1888, p.11); BGS: R 2968-75.

At this locality Rhodes collected: *Porosphaera globularis* (Phillips), *Nodelea durobrivensis* Gregory, *Pycnodonte* sp., *Echinocorys* ex gr. *conica* (Agassiz) [precursor of *E. conica* s.s. characterising uppermost *quadrata* Zone in southern England], indet. micrasterid.

**MARLINGFORD** [137 093]; Rowe loc. 181.

Rowe MS: "small surface of pasty chalk above talus, green with age. Flints large and suggestive of *mucro*. *R.(hynchonella) limbata* 3 [not found in BMNH]. (Flint) meal from this pit includes *Cidaris subvesiculosa*, *Kingena lima*, *Terebratulina striata*. Strange that both *Echinocorys* and *B. mucro* should be so rare here."

The section was assigned by Rowe to the *mucronata* Zone, but later by Brydone (correctly) to the Zone of granulated *Actinocamax*.

**ALGARSTHORPE** [1446 0888]; Rhodes loc. 25, Rowe loc. 182.

Blake (1888, p.11); BGS: R 2976-80.

No section is now visible. Rhodes collected the following zonally undiagnostic fauna: *Porosphaera globularis*, indet bryozoa, *Glomerula gordialis* (Schlotheim), *Cretirhynchia* sp. Rowe recorded "*Serpula canteriata* 2", and assigned the pit to the *mucronata* Zone for no stated reasons. However, this locality lies west of the proven *quadrata* Zone locality Rhodes 26, and so must belong to the latter zone. This pit may be the unidentified Brydone locality 'Bauburgh Limekiln', which yielded *Gonioteuthis* sp. [NCM].

**BAWBURGH**, south of the Three Cornered Plantation [1464 0956]; Rowe loc. 180.

BGS: CJW 3820-29.

Rowe MS: "Small surface in very pasty Chalk. Flints very large chiefly black with no cortex. No continuous course can be traced. *Echinocorys* (Tharston form) [BMNH E41297], *Kingena lima*, *B*.*mucro* 2, *Serpula canteriata*, *Rhynchonella limbata*, *lentiformis*, *plicatilis*, *Cardiaster ananchytis*. *Echinocorys* notably rare and this the only example showing shape clearly suggests the Tharston form [the BMNH specimen is crushed and the shape is therefore difficult to determine]. This gives the Tharston line [for discussion of the terms 'Tharston form' and 'Tharston line' see below p.21]."

At this locality the author collected: *Conorca* cf. *turbinella* (J. Sowerby), *Ditrupa* (*Ditrupa*) sp., *D*. (*Pentaditrupa*) sp? or *Hepteris* sp?, *Glomerula gordialis*, *Cretirhynchia* aff. *norvicensis* Pettitt [undescribed small cuboidal form characteristic of high *quadrata* and basal *mucronata* zones], *Belemnitella* ex gr. *praecursor* Stolley, marginal of *Metopaster* or *Recurvaster*; *Echinocorys* ex gr. *conica* [relatively depressed flat-based variant, reminiscent of *E*. *subconicula* Brydone from the basal *mucronata* zone of Hants]. The locality was attributed by Rowe to the *mucronata* Zone, but the faunal assemblage is somewhat anomalous and its stratigraphical position cannot be stated with certainty. It is significant that the chalk appears reconstituted with much included pelletal material and slivers of flint, and it is therefore possible that this section is cut in a raft. The section examined earlier is now partly obscured by tipping and may well be now completely overgrown (1975).

**BAWBURGH** [1494 0879]; Rhodes loc. 26.

Blake (1888, p.11: "Bauburgh, nearly ¹/4 ml NW by N of the church"); BGS: R 2981-88.

Rhodes collected cuboidal Cretirhynchia aff. norvicensis (2), Gonioteuthis sp. Whether disturbed Chalk or not, this locality has yielded unequivocal Gonioteuthis suggesting that all the anomalous or zonally unassignable localities to the west should be placed in the quadrata zone. No Chalk is exposed at present, although it is probably only just below the talus.

**BAWBURGH ROOKERY** [1610 0906]: (no Rowe or Rhodes locality number); Peake list no. 286.

Brydone (1931, p.48: "the Rookery, Bawburgh"); BGS: CJW 3830.

This pit is questionably the locality from which Brydone collected a Gonioteuthis cf. quadrata gracilis (Stolley) labelled 'Bauburgh Farm' [NCM]. A single Belemnitella sp. juv. cf. praecursor [CJW 3830] was collected, but is too fragmentary for exact zonal assignment. The chalk in this pit is largely reconstituted and is probably part of a raft. Further evidence that this locality may be cut in a raft is provided by the relatively high topographical level at about 23m OD compared with Rowe locality 179 some 275m to the south-east at [1635 0894] which formerly exposed Chalk below sand at less than 15m OD. From the latter locality which was presumably in in situ Chalk of very high quadrata or basal mucronata Zone age, Rowe recorded a large "B. mucro" - i.e. possibly a large Belemnitella ex gr. praecursor; unfortunately this specimen cannot be found in the Rowe collections in BMNH.

(ii) River Tiffey valley (a tributary of the Yare)

**CARLTON FOREHOE** [either 0845 0520 - gravel shown on Old Series Geological map - or 0825 0528].

Blake (1888, p.11); BGS: R 3041-7.

Memoir: "At Four Hill Wood, half a mile S.W. of the church, there is a pit showing Boulder Clay, resting on rubbly yellowish chalk with flints, 12 feet [3.6m] thick."

R 3041-47: ventriculitid and another indet. sponge in flint, Ditrupa (Pentaditrupa?) sp., hinge fragment of Sphenoceramus sp., Gonioteuthis sp. juv. indet., Echinocorys sp. [medium-sized depressed domed variant of uncertain stratigraphical position]. Despite the position of this locality in relation to presumed quadrata zone localities to the north and east, the occurrence of the Sphenoceramus hinge is anomalous, and suggests a much lower level in the broad zone of Gonioteuthis, possibly even in the equivalent of the pilula zone.

(iii) Wensum valley, from west to east

**ATTLEBRIDGE** [134 165]; Rhodes loc. 16, Rowe loc. 168.

Blake (1888, p.7: "large pit $^3/8$ ml S.E. of church");
BGS: R 2937-39

Memoir: "20 ft+ [6m+] white soft thinly bedded chalk; numerous irregular-shaped black flints with a very thin white coating." Rhodes collected the following: Porosphaera globularis, Chlamys cretosa (Defrance), Echinocorys sp. with adnate Porosphaera sessilis Brydone, octocoral rooting bases, Pycnodonte sp.

Rowe MS: "old pit of medium size, chalk much ironstained, broken but fairly firm. Flints few and small and black, solid with skin cortex. Belemnites [BMNH C43330; 43349-50: Gonioteuthis sp. juv. or G. quadrata gracilis] well preserved, granulations clearly of granulatus type."

**ATTLEBRIDGE** [1418 1570]; Rhodes loc. 17; Rowe loc. 169.

Blake (1888, p.7: "250 yds E of Attlebridge Hall"); BGS: R 2940-1

Memoir: "18 ft [5.5m] of chalk, white-weathering, yellowish in places, with many flints and a few paramoudras. Thin bedded". Rhodes collected two specimens of Cardiotaxis cf. heberti (Cotteau) in flint.

Rowe MS: "Flints in regular courses and much larger than in 168, otherwise same. Chalk same also but much blockier. 3 Rhynchonella limbata [not in BMNH]; Cretirhynchia aff. norvicensis [cuboidal form]: B93433]; Isocrania cf. borealis borealis Ernst [magnificent specimen with both valves articulated: B93432], Gonioteuthis sp. [C43331]."

**ATTLEBRIDGE** [1503 1526]; Rhodes loc. 18 (not examined by Rowe)

Blake (1888, p.8: "1⁵/8 ml from church"); BGS: R 2942-44

This pit, which formerly exposed Chalk underlying sand, is now obliterated. Rhodes collected a limited fauna comprising Neoliothyrina? sp. nov.? [rolled pedicle valve] and Gonioteuthis sp. [apex fragment, with weak granulations]. In contrast to the adjacent Deighton Hills locality, described below, this was probably in situ chalk rather than a raft.

**DEIGHTON HILLS** [149 156]; Rowe loc. 175 ("disused pit down drift by keeper's cottage").

Brydone (1932: "½ ml S.W. of Spring Farm, Attlebridge").

Rowe MS: "Chalk rather massive and flints of large size. This is almost certainly in base of mucro". ["Rhynchonella limbata" was the only fossil recorded by Rowe: this specimen cannot be found in BMNH.]

Brydone (1932) recorded an overgrown pit exposing 4.5m of Chalk of which the lowest 2.7m were yellow and the highest 1.2m white. He considered that the pit spanned the zonal boundary between the soft yellow chalk typical of the quadrata Zone near Attlebridge and the whiter, more massive Chalk of the base of the mucronata zone as exposed to the west of Taverham, a zonal assignment which was reinforced by his finding two [NCM: indeterminate] supposed Belemnitella mucronata presumed to have fallen onto the talus from the topmost beds.

Re-examination of this locality by Mr. N.B. Peake and the author in 1975 has shown that about 12m of section must have been visible formerly. All the exposed chalk is pellety in character and apparently reconstituted, this pellety chalk being proved by digging to a depth of about 1m below the floor of the pit. Towards the top of the section there are a number of very large nodular flints of a type which occur at certain horizons in the Paramoudra Chalk subdivision of the mucronata Zone, although none of these could be described as paramoudras. There is no obvious bedding, and the whole section is overlain by what appears to be an equivalent of the Norwich Crag with, locally, a basal Stone Bed. No fossils were found despite prolonged searching. Although there is little doubt that this must be the same locality as examined by Rowe and subsequently by Brydone, it is difficult to reconcile the latter's description with the section which can be seen at present. The whole appearance of the section is reminiscent of the raft of Paramoudra Chalk constituting the Runton Erratic on the Norfolk coast (Peake and Hancock 1961, p.325). The hypothesis that this section might be a raft finds support in the fact that gravel survey boreholes NW 24 and NE 4 to the north and north-east of the pit proved 17.7 and 20.1m respectively of glacial deposits overlying Chalk (Nickless 1973), this gravel presumably being banked up against the northern face of an erratic. Furthermore, although the Chalk surface in the pit itself is at circa 24m OD, it must rise abruptly northwards, since the adjoining well no.147/54 encountered Chalk at circa 30m OD beneath 6.7m of gravels (Nickless ibid.). If the pit can be shown to be part of a raft, it follows that the whole of the Attlebridge Hills feature to the north-west may be explained in the same way.

## RINGLAND

Numerous small pits formerly open in and to the north-east of the village were examined at various times by Rhodes, Rowe and Brydone, but from the limited locality information it is very difficult to state their exact positions, this applying particularly to Rhodes locs. 20 and 22. Rhodes loc. 23 (Blake 1888, fig. 4 "just S. of the church and by the road", which yielded only Glomerula gordialis [R 2965-67] of no stratigraphical significance, is clearly the now obliterated pit at [1336 1398]. Rhodes 21, "³/8 ml ENE of the church" [R 2957-60] yielded Porosphaera globularis and an apical half of a moderately strongly granulated Gonioteuthis, and may have been at [1398 1430]. This pit is possibly Rowe 172, in which case the following MS comment can be added: "Old pit of medium size with small mainly surface flints same as last with same undulation. Soft pasty chalk of yellow colour. These pits (in Ringland area) are all glaciated - may be either zone but Porosphaera looks like quad."

It should be noted that Peake and Hancock (1961, p.14) stated that many small pits around Ringland formerly exposed Chalk of their Basal mucronata Chalk subdivision, but it is possible that pits on the east side of the Wensum valley were intended - see discussion regarding Brydone's positioning of the quadrata - mucronata zonal boundary, below, pp.22-23.

**MORTON** [1300 1465]; Rhodes loc. 19.

Blake (1888, p.10: "limekiln ½ ml NW by N of Ringland church");
BGS: R 2945-53, CJW 3831.

Rhodes collected the following fossils: Proliserpula ampullacea (J. Sowerby), indet. oyster, Gonioteuthis quadrata with markedly quadrate alveolus and adnate Atreta nilssoni (Hagenow).

In 1975 this locality still exposed a 3-4 metre section of comparatively undisturbed Chalk with irregular courses of flint; the most conspicuous feature was a dominant course of distinctively 'bent' flints with black cores and a thin grey skin some 1.5m below the top of the section. Apart from a specimen of Porosphaera cf. nuciformis Hagenow, the only fossil noted was a fragment of Echinocorys test.

**RINGLAND** [1340 1314]; Rhodes loc. 27.

Blake (1888, p.10: "5/8 ml S of church"); BGS: R 2989-3005;
CJW 5309-17.

This pit exposed a circa 4m section in 1973, although the lower part was obscured by talus. The Chalk exhibited minor folding but was otherwise relatively undisturbed. There were three flint courses: a pair of thalassinoid burrow-form flints near the top of the section, and a semi-continuous tabulate flint near the base. Most of the Rhodes material was collected from flints, but none of the flints observed in 1973 contained any fossils, and it is therefore conceivable that he was collecting from a lower horizon. The fauna comprised Coscinopora infundibuliformis Goldfuss, Porosphaera globularis [including large form], Ditrupa sp., Coelosmilia sp. juv., indeterminate rhynchonellids, including costate form and a Cretirhynchia ex gr. arcuata-limbata, Neoliothyrina? sp. nov.?, Gonioteuthis quadrata gracilis and G. sp., Echinocorys conica, E. ex gr. conica [precursor of E. conica s.s. and related forms characterising uppermost quadrata Zone in southern England], E. cf. marginata (Goldfuss), indeterminate cidarid radioles. This assemblage clearly indicates the top of the quadrata Zone, and it is probable that this is the highest exposed quadrata Zone Chalk in Norfolk.

**RINGLAND** [1395 1253]; Rhodes loc. 28.

Blake (1888, p.10: "1 ml SSE of church"); BGS: R 3006-09.

At this now overgrown locality Rhodes collected a small fauna comprising Gonioteuthis cf. quadrata gracilis; Echinocorys ex gr. conica [high quadrata Zone precursor]. In addition a Micraster cast and a Ventriculites were recorded in the register, but the first was rejected at the time and the second is missing.

This locality may possibly be Rowe 171, although it is not in the position where Rowe marked it on his field map. The fauna indicates a very high level in the quadrata Zone, comparable to that in the preceding Rhodes loc. 27.

## B. The Belemnitella mucronata Zone

### Subdivisions and biostratigraphy

The six-fold essentially palaeontological scheme of subdivision of the Norfolk mucronata Zone established by Peake and Hancock (1961; 1970) derived much of its inspiration from the researches of earlier workers, notably Rowe and Brydone, both of whom were able to examine far more sections than are available at present. This earlier research is of considerable interest and includes information which has subsequently been lost sight of, particularly with reference to faunal belts and fossils of restricted stratigraphical distribution. Following the publication (1970) of the updated version of Peake and Hancock's paper knowledge of the mucronata Zone has considerably advanced, largely as a result of the availability of temporary sections in critical parts of the succession. In addition, it is now known that the Micraster assemblages from the upper part of the mucronata Zone are quite distinct from those from lower horizons within the zone, and find their closest parallels with assemblages from near the Campanian-Maastrichtian boundary on the continent (Schulz 1978). All these advances have led to a reassessment of the individual contributions of Rowe and Brydone, which are considered here in some detail, in order that the Peake and Hancock scheme and the faunal belts now tentatively recognised can be seen within a framework of evolving ideas on the classification of the Norwich Chalk.

## Phase I (19th Century)

During the 19th Century the richly fossiliferous nature of the Norwich Chalk became apparent, and fossils were actively collected by local geologists of whom the most notable were T.G. Bayfield, Robert Fitch, John King and S. and S.P. Woodward. The Bayfield Collection was acquired by BMNH; the Fitch and King Collections are preserved in NCM; while material from the Woodwards is to be found in NCM, BMNH and BGS. Since at that time it was apparently not generally appreciated that different pits exposed different parts of the Norwich Chalk, much of this magnificant material is poorly localised by modern standards, with at best a vague locality such as 'Thorpe' or 'Trowse'. Also, following the dispersal of the collections, most of the limited locality information has been lost or mislaid, although the detailed lists given in the first edition of the Norwich Memoir (Woodward 1882, pp.10-19) go some way towards making up for this deficiency. The main pits then extant were (in alphabetical order); Carrow, Catton, Costessey, Drayton, Earlham, Eaton, Harford Bridges, Magdalen Chapel, Postwick, St. Gile's Gate, St. James', Stoke Holy Cross, Stonehills, Thorpe Hamlets = Bishop's Bridge pit = Lollard's pit, Thorpe Limekiln, Thorpe Tollgate, Trowse and Whitlingham. Many oysters and baculitids were collected from the so-called 'Baculite pit' near the City Gaol, while the Lollard's pit was the site of the discovery of large numbers of bones and teeth of Mosasaurus. Many of the pits listed above were available to 20th century workers such as Rowe and later Brydone (notably Eaton, Harford Bridges, Magdalen Chapel, Stonehills, Thorpe and Whitlingham), whereas others such as St. Gile's Gate, Thorpe Hamlets, and the Lollard's pit either disappeared or became inaccessible.

**Phase II (Rowe)**

During 1905-1915, Dr. A.W. Rowe examined and zoned all the Norfolk chalk pits known to him, with particular attention being paid to the pits in and around Norwich. It is apparent from correspondence towards the end of his life that Rowe intended to prepare a paper on the stratigraphy and subzonal classification of the Norwich Chalk, but no MS of such a work has been found. There are, however, three surviving field notebooks [preserved in the Palaeontology Library BMNH] dealing wholly or partly with this area, summaries of faunas from the main fossiliferous localities and a quantity of MS notes associated with his collections [also in BMNH], some of which provide information not found in the notebooks. It is almost certain that at least one notebook dealing with the Norfolk Chalk has been lost and was never passed to the BMNH, since the earlier part of his numbered sequence of pits [prior to loc. 138] is not represented by any field observations.

From Rowe MS and, in particular, from information given by him to (the late) Mr. C.P. Chatwin of the then Geological Survey prior to his collecting trip to the Norwich area in 1925, it can be seen that Rowe placed the main fossiliferous localities localities in the following order:

(highest) Loc. 153 Thorpe St. Andrews
164 Whitlingham
160 Mousehold (= Magdalen Chapel of earlier references)
159 New Catton (Attoe's pit)
161/162 Harford Bridges (lowest but one in the series and with the hardest chalk)
(lowest) 49 Tharston (= base of mucronata Zone)

Rowe's information to Chatwin notes that "the fauna of Thorpe is strangely different from Mousehold. The latter cannot be more than 100-120 ft [30.5-36.5m] lower in level. Whitlingham is intermediate.

Harford Bridges is in great contrast with other Norwich Chalk in that it is firm and blocky.".

In addition to these six localities, Rowe recognised that locs. 155 and 156 (the two Dereham Road pits, Stonehills and Earlham Grove respectively) and also 158 (Cunnell's pit, Newmarket Road) "occupied a very clear subzonal horizon in that they have no less than three echinoderms restricted to that level. Below the middle of the *mucro.* subzonal series". Two of the three echinoids referred to are his '*Conulus minor*' and '*Echinocorys bayfieldi*', while the third cannot be identified. *Conulus minor* Rowe MS was referred by Ernst (1971, p.220) to a small form of the Maastrichtian species *Galerites sulcatoradiatus* (Goldfuss), but has subsequently been assigned by Schulz (1985) to *Echinogalerus*? *hemisphaericus* (Desor). Dr. A. Smith (BMNH: pers. comm.) considers that these small echinoids should be provisionally cited as *Galerites*? *minor* Rowe MS. *Echinocorys bayfieldi* Rowe MS is the *Galeola* sp. nov.? of Brighton (1939), originally described on the basis of three specimens from Eaton Limeworks [i.e. Rowe loc. 158] and now attributed to *Galeola papillosa basiplana* Ernst (Ernst 1971 Abb.23, figs. 2-6). According to Rowe MS, these two echinoid occurred in a band - the 'minor-bayfieldi band' - some 12 ft [3.6m thick, which was located near the base of all three pits, the mai concentration being at the base of the band immediately above a larg flint, below which they were rare. A comparable association is foun in the echinoid-rich band below (and for some metres above) flint Z a the junction of the Eaton Chalk and the stratotype Weybourne Chalk a Weybourne Hope (Peake and Hancock 1970, p.339D-E). Ernst (1971 p.176) has correctly pointed to the possibility of the Eaton and flin Z horizons being equivalent - which thus has the effect of placing th greater part of the succession in the three Norwich pits into th

Weybourne Chalk. Rowe also commented on the 'wonderful abundance' of *R*.(*hynchonella*) [i.e. *Cretirhynchia*] *lentiformis* in loc. 158, and considered the possibility that "they might mark an horizon".

Rowe did not attempt to subdivide the lower part of the *mucronata* Zone succession, but he noted that two marker 'lines' could be traced from pit to pit across the county, and used in correlation. The occurrence of a distinctive 'Tharston form' of *Echinocorys* [*Echinocorys conica*] constituted the 'Tharston Line' - named after Tharston (49) [1490 9560], where well-preserved specimens of this species were found in abundance. Based on a single crushed *E. conica*, he also recognised this 'line' at Bawburgh (180) [1464 0956], a section which may well be cut in a raft of reconstructed Chalk. His 'Cley Line', named after Cley Green (82) [048 433], near the coast, was identified by the occurrence of the bryozoan '*Volvolunulites*' [*Volviflustrellaria*] *taverensis* (Brydone), which he noted in the Norwich area at Taverham (186) [ 1616 1408], Drayton (151) [1801 1383] and Bowthorpe Hall Farm (177) [1802 0903]. Rowe considered that Tharston was situated at the base of the *mucronata* Zone, whereas it appears probable that it occupies a higher stratigraphical level, and certainly above the belt of abundant *V. taverensis*.

In the higher part of the succession, Rowe noted a bed of hard yellow chalk [the Catton Sponge Bed of modern terminology] near the top of Attoe's pit (159) [231 111] and commented on the abundance and large size of *R(hynchonella) plicatlis* and var. *octa.(plicata)*. [*Cretirhynchia norvicensis* Pettitt], as well as *T(erebratula) carnea* [*Carneithyris*]. At Thorpe (153) [2755 0900], his highest *mucronata* Zone locality, he noted the abundance of *Micraster* and *Epiaster* [*Micraster ciplyensis* Schluter].

Apart from his placing of Tharston at the base of the *mucronata*

Zone, and the pits with the '*minor-bayfieldi* band' above rather than below Harford Bridges, Rowe had a very clear idea of the general succession in the Norwich area, and was the first worker to draw attention to the major faunal change at the Catton Sponge Bed. It is to be regretted that his stratigraphical researches were never published.

### Phase III (Brydone)

During the period 1896-1939, R.M. Brydone carried out extensive research into the Chalk of Norfolk, with particular reference to the crinoid zones, the so-called 'Norwich Chalk' and the Maastrichtian Chalk of Trimingham. Towards the end of this period he published a number of short but important papers in which - virtually independently of the unpublished work of Rowe - he outlined his views on the stratigraphy and succession of faunas in the Norwich Chalk. The main conclusions can be summarised as follows:

(i) Brydone (1922) noted the relative abundance of *Micraster* [*M*.*glyphus*] and *Epiaster* [*M*. (*Isomicraster*) *stolleyi* Lambert] in the Weybourne Chalk [used informally in the sense 'Chalk at Weybourne'] compared with other parts of the *Belemnitella* *mucronata* Zone.

(ii) Brydone (1930) established that the junction between the Zone of 'granulated *Actinocamax*' [the undivided *Gonioteuthis* Zone of present usage] and the *Belemnitella* *mucronata* Zone could be drawn between Ringland (with *Actinocamax* *quadratus*) and Taverham Park [i.e. Taverham Park Lodge pit, probably = Rowe loc. 170] (with *B*. *mucronata*), with the boundary line approximating to the line of the Wensum valley at this point. He considered that this line could be traced from Spring Farm, Attlebridge (Rowe loc. 175) [149 156] to the Rookery, Bawburgh [1610 0906] and on to Little Melton. Whilst Brydone's assumption on the position of this boundary is probably broadly correct, it should be pointed out that two of his critical localities, namely Spring Farm and the Rookery, are probably 'rafts' of Chalk rather than part of the *in situ* succession (see pp.13 and 11), and that the belemnites from Taverham Park Lodge are probably late *Belemnitella* ex gr. *praecursor* such as characterise the *Gonioteuthis quadrata* - *Belemnitella mucronata* zonal boundary in Northern Ireland and southern England (Hants-I.O.W.), but which cannot be stated to be diagnostic of the higher zone.

Within the *mucronata* Zone itself, Brydone recognised that a second line, roughly parallel to the first and drawn from Hellesdon Bridge [198 100] to Cringleford Bridge [200 060], divided localities to the west such as Taverham [1616 1408], Costessy [NGR not known], Drayton [174 131] and Bowthorpe [1760 0908 or 1802 0903] where he did not find *Magas pumilis*[1] from localities to the east where this brachiopod occurred. West of this line he recorded

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[1] It should be noted that *Magas pumilus* J. Sowerby was originally described from the Maastrichtian 'White Chalk with *Ostrea lunata*' of the Norfolk coast, and that *Magas pumilis* sensu Brydone from the lower part of the Norwich *mucronata* Zone belongs to an undescribed species referred to here as *Magas* sp. *nov*. (see Davidson 1852, pl.2, figs. 5-11). Other *pumilis*-like forms in the lower part of the *mucronata* Zone may prove to be ancestral to *M*. *pumilis* s.s, but these are quite distinct from *M*. sp. nov. with its characteristic upright or even back-tilted umbo and open delthyrium.

Kats (*in* Krymgolts *et al*. 1974, pp.266-7) has referred the specimens figured in Davidson (*ibid*., pl.2, figs. 6-8) to *Rhynchorina plena* sp. nov., which he described from material from the higher part of the Upper Campanian [local Zone of *Belemnitella langei langei*] of the Donets Basin, USSR. It is not possible, however, to decide from the figures and limited description whether the Donets Basin species is conspecific or even congeneric with the Norwich Chalk *Magas* sp. nov, and the name has therefore not been adopted here.

*Membranipora traverensis* [subsequently assigned by him to *Volviflustrellaria*] at Taverham [1418 1328]. Drayton and Cringleford [presumably, from Brydone 1939, Newfound Farm 189 069], the first two being localities on Rowe's `Cley Line', which was likewise identified by the occurrence of *Volviflustrellaria*. Brydone considered that *Membranipora taverensis* was probably restricted to the "basal" *mucronata* Chalk in Norfolk and would serve to identify it. He thus effectively placed all localities west of Cringleford Bridge in his "basal" *mucronata* Chalk, in marked contrast to the concept of this subdivision adopted by Peake and Hancock (p.27).

(iii) Brydone (1932) commented that the granulated *Actinocamax*-*Belemnitella mucronata* zonal boundary occurred within the pit ½ ml south-west of Spring Farm, Attlebridge, since there was a change from yellow chalk below to white chalk above, and he found two loose specimens of *Belemnitella mucronata*. As discussed above (p.14), this lithological distinction cannot be confirmed, and the true stratigraphical provenance of the two belemnites is questionable.

(iv) Brydone (1938)

(1) introduced (p.5) the term 'Beeston Chalk' for that part of the Cromer to Weybourne Chalk which lay east of Sheringham, but excluding the Maastrichtian Chalk of Trimingham,

(2) elaborating on his previous observation (Brydone 1922), recognised (p.11) the stratigraphical equivalence of the Chalk between Sheringham and Weybourne with the Chalk at Hartford [Harford] Limekiln on the basis of the occurrence of *Serpula accumulata* S. Woodward [*Bipygmaeus*? *accumulata*], depressed forms of *Echinocorys* [*E*. *gibba oviformis* Lambert] and the relative abundance of *Micraster* and *Epiaster*],

(3) drew attention (pp.11-12) to the major faunal change at the level of the sponge bed in Attoe's [231 111] and Campling's [2289 1094] pits at Catton - i.e. the Catton Sponge Bed, as subsequently defined. The pre-sponge bed succession, which he equated with the Chalk between Weybourne and Sheringham, was stated to be characterised by *Micraster*, *Epiaster* and *Cardiaster heberti* [*Cardiotaxis*], whereas in the Chalk above the sponge bed, which he associated with the Beeston Chalk, *Micraster* and *Epiaster* were rare or absent, and *C. heberti* was replaced by *C. ananchytis* Leske. The species referred to *C. ananchytis* is *Cardiaster cordiformis* (S. Woodward), the genotype of *Cardiaster*, which Forbes (1852) incorrectly placed in the synonymy of the Maastrichtian *C. granulosus* (Goldfuss). The high Upper Campanian *Cardiaster cordiformis* differs from the latter species in the structure of its plastron, a feature recognised by Ernst (1972, Abb. 20, fig. 12), who introduced the name *C.* aff. *granulosus*. Clear figures of this widely distributed and stratigraphically restricted species were given by Forbes (1852, pl.9), and also by Wright (1862-84, pl.59, fig. 2)

(4) noted (pp.12-13) the relative abundance of the small race of *Rhynconella* [sic] *limbata* [*Cretirhynchia lentiformis* (S. Woodward)] in the Chalk between Weybourne and Old Hythe, Sheringham and in the Chalk of Harford [2200 0569] and Eaton [208 063], commenting that east of Old Hythe this race seem to have practically disappeared with its place being taken by *R. reedensis* Etheridge [*Orbirhynchia*, but small specimens of *Cretirhynchia woodwardi* Pettitt may also be included here].

(5) introduced (table on p.16) the term 'Eaton Chalk', which he stated to be characterised by *Membranipora eleanorae* Brydone [*Hoplocheilina*], and placed between the Harford Chalk and the Chalk

characterised by Volviflustrellaria taverensis.

(6) commented that the 'cast bed' at Thorpe (Old Limekiln) was probably a local development of the sponge bed at Catton.

(v) Brydone (in Brighton 1939)

In notes quoted by Brighton, Brydone carefully defined his 'Eaton Chalk' - for which the implied stratotype is Eaton Lime Works - as being characterised by:

(1) a large form of Echinocorys scutatus of strictly conical shape and with a flat and circular base; (2) abundance of Membranipora eleanorae, a species only known otherwise occurring very sparingly in the chalk with Volviflustrellaria taverensis at Taverham; (3) complete absence of V. taverensis - which he considered seemed to "mark a bed close to the base of this (mucronata) zone, but probably not reaching quite to it".

In summary, Brydone laid the foundations of the pre-Catton Sponge Bed stratigraphy in current usage, but failed to appreciate that only the bottom part of Eaton contained his Eaton fauna. However, in marked contrast to Rowe, his concept of the post-Catton Sponge Bed succession was confused, and it is clear that he did not recognise any faunal or lithostratigraphical distinction between the Beeston Chalk and the unit subsequently separated by Peake and Hancock (1961) as Paramoudra Chalk.

**Phase IV** (Peake and Hancock 1961; 1970; Peake in Hancock 1972)

Peake and Hancock, basing their ideas partly on Brydone's published work, but mainly on their detailed stratigraphical collecting and examination of museum material, established the six-fold subdivision of the Norfolk mucronata Zone in current use. These subdivisions comprise, in ascending order, Basal mucronata Chalk; Eaton Chalk; Weybourne Chalk; Catton Sponge Bed; Beeston Chalk; and

Paramoudra Chalk.

Of these subdivisions:

(1) The Basal mucronata Chalk was adopted from Brydone, and stated to be characterised by abundant Volviflustrellaria taverensis and by the absence of Galeola, the latter being typical of the overlying Eaton Chalk. On this basis, the upper limit of the subdivision was placed at or below the base of Drayton (Peake and Hancock 1970, p.339D), whereas Brydone expressly remarked (1930) that all localities west of Cringleford Bridge, including Drayton fell within his "basal" mucronata chalk. Furthermore, the description 'abundant Volviflustrellaria' does not obtain throughout the "basal" mucronata chalk sensu Brydone, but applies only to the horizon represented by the Taverham pit.

(2) The Eaton Chalk was likewise adopted from Brydone's scheme, but its lower limit did not agree with Brydone's concept [see discussion above and p.52]. The upper limit was taken at flint Z at Weybourne, whereas it is now known that several of the distinctive elements of the Eaton fauna range higher, probably up to flint X, which appears to mark the local upper limit (excluding conica-like forms in the Beeston Chalk) of Echinocorys conica.

(3) The Weybourne Chalk was a new term to cover what Brydone variously referred to as 'Weybourne to Sheringham Chalk' and/or Hartford (Harford) Chalk, with its upper limit taken at the base of the Catton Sponge Bed.

(4) The Catton Sponge Bed was a new term for the hard bed formerly seen at Attoe's pit and still visible at Campling's pit, Catton (Catton Grove), which, for both Rowe and Brydone, appeared to mark a major faunal change. In the 1970 revision (p.339E-F), Peake and Hancock emended their original concept to include several higher hard

beds although, by so doing, they obscured the fact that the faunal change occurs at the horizon of the lowest of the three hard (sponge) beds which they recognised both on the coast at Sheringham and in the pit at Catton. Even this lowest sponge bed is now known (p.62) to comprise two closely spaced sponge beds in the stratotype section; the upper of these is marked by a mineralised surface overlain by soft glauconitised pebbles and a lag accumulation of reworked belemnites ('belemnite graveyard'). It is this hardened surface which should be taken as the top of a restricted Catton Sponge Bed, which itself marks the upper limit of the Weybourne Chalk.

(5) The Beeston Chalk of Brydone was restricted to the succession lying between the Catton Sponge Bed(s) at Sheringham and a hard bed which crops out on the shore about 180m east of West Runton. Of the Norwich pits, Whitlingham and Thorpe were originally (Peake and Hancock 1961) placed in this subdivision, but they were subsequently correctly reassigned (1970, p.339F) to the overlying Paramoudra Chalk.

(6) The Paramoudra Chalk was a new term to cover the 23m of chalk with paramoudras (see p.37) between the now restricted Beeston Chalk and the top of the mucronata Zone, this unit equating in part with the "chalk near Cromer", which Brydone (1906) described as "wonderfully barren". Peake and Hancock (1970, p.339F) took the base of this subdivision at the hardground near West Runton, but it is unclear whether they intended this bed to be regarded as marking the top of the Beeston Chalk, or as the basal bed of the Paramoudra Chalk. It would appear preferable to treat this hard bed, analogous to the Catton Sponge Bed, as marking a period of still-stand and erosion terminating the deposition of the underlying sequence. The upper limit of the Paramoudra Chalk was not defined, but can probably be taken (on the coast near Overstrand) at the horizon of (derived

blocks) of a chalkstone with abundant Echinocorys pyramidata Portlock sensu Wright and sporadic Belemnitella (Peake and Hancock 1970, p.339G; Fletcher and Wood 1978, p.110). There is no indication of this bed in the Norwich area, although the distinctive Echinocorys is known from temporary sections east of Whitlingham.

**Phase V** (recent research)

Further observations can be made with regard to the biostratigraphy of the brachiopods, bivalves and echinoids, which are relevant to producing a scheme of subdivision of the Norwich mucronata Zone.

(1) Brachiopods:

(i) Cretirhynchia lentiformis (possibly including juvenile and/or micromorphic forms related to C. norvicensis: Mr. A. Pitchford, pers. comm.) cuts out in the lower part of the Weybourne Chalk. The separation by Leeder (1968) of two informally named variants (form a and form b) of C. lentiformis has not been followed here.

(ii) Carneithyris carnea (J. Sowerby) and Cretirhynchia arcuata Pettitt enter a short distance below the Catton Sponge Bed, and first become abundant immediately above it in the basal beds of the Beeston Chalk. The entry of these species permits the subdivision of the higher Weybourne Chalk (above the beds with C. lentiformis) into two parts.

(iii) Cretirhynchia woodwardi cuts out sharply at the terminal surface of the main Catton Sponge Bed at the top of the Weybourne Chalk (see p. 62).

(iv) Rhynchonellid brachiopods of Maastrichtian aspect such as Cretirhynchia aff. magna Pettitt and C. aff. retracta (Roemer) enter in the higher part of the Paramoudra Chalk.

(2) Bivalves:

(i) Plagiostoma marrotianum (d'Orbigny) and Chlamys mantelliana (d'Orbigny) are apparently restricted to the pre-Catton Sponge Bed succession, the latter species being particularly common in the middle part of the Weybourne Chalk.

(ii) Large individuals of the long-ranging species Hyotissa semiplana (J. de C. Sowerby) are abundant in, and characterise the middle part of the Weybourne Chalk.

(iii) Pycnodonteine oysters, broadly attributable to Pycnodonte (Phygraea) vesicularis (Lamarck), range throughout the mucronata Zone and into the Maastrichtian, but they exhibit several different stratigraphically restricted morphotypes (see pp. 34 and 37). In general, there is a progressive size increase upwards, with the largest and thickest shelled individuals characterising the Paramoudra Chalk and the Maastrichtian.

(iv) Quite apart from its distinctive fauna (p. 36), the Beeston Chalk is readily recognisable from the occurrence of laterally continuous belts of chalk rich in large pieces of Inoceramus shell; the larger pieces are commonly associated with, and provided a substrate for, the oyster Ostrea triangularis S. Woodward.

(v) There is a significant change in the larger pectinids in the post-Catton Sponge Bed succession. The Beeston Chalk is characterised by two distinct forms (possibly separate species) of the long-ranging Chlamys cretosa (Defrance) (see p. 71); in the overlying Paramoudra Chalk these forms are apparently absent, and are replaced by forms near or conspecific with the Maastrichtian species C. denticulata (Hagenow).

(3) Echinoids

(i) Micraster glyphus and M. stolleyi apparently cut out at the top of the Catton Sponge Bed, together with Cardiotaxis heberti. In the overlying Beeston Chalk, micrasterids are extremely rare, and no determinate specimens have been collected. Specimens of M. glyphus in the Rowe Coll. [BMNH] marked W. may have come from the Weybourne Chalk of Weybourne rather than the lower Paramoudra Chalk of Whitlingham (see p. 74).

(ii) Micrasterids from the Paramoudra Chalk of Whitlingham and, particularly, Thorpe, cited by Nichols (1959) and Stokes (1976) as Micraser stolleyi and forms transitional between M. stolleyi and M. glyphus are now attributed to Micraster ciplyensis Schlüter [Schlüter 1897, pl.2, figs. 1,2; Lambert 1911, pl.2, fig. 16] - see dicussion by Fletcher and Wood (1978) Schulz (1978).

It is now possible to recognise a number of well characterised faunal belts within the Peake and Hancock scheme. Because of ambiguities which have arisen from the differing interpretations given to the Basal mucronata and Eaton Chalk subdivisions by Brydone and by Peake and Hancock (see p.27), it is suggested that a new term, the Pre-Weybourne Chalk, should be introduced for this part of the succession. It must be emphasised that the various faunal belts cannot yet be satisfactorily delimited in terms of the local lithostratigraphical succession, but that they do appear to apply to the *mucronata* Zone of other areas, notably Northern Ireland.

The revised classification of the Norwich *mucronata* Zone tentatively proposed in this paper, together with the palaeontological criteria defining the various faunal belts, is set out below.

**Pre-Weybourne Chalk**

This subdivision embraces the Eaton and Basal *mucronata* Chalk of the existing classification. The Pre-Weybourne Chalk is relatively poorly exposed, but examination of museum material and limited material collected during the re-survey in conjunction with the work of Rowe and Brydone suggests that the following faunal belts can be recognised at least in the Norwich area:

**Pre-Weybourne$_1$**

*Volviflustrellaria taverensis* is not recorded: this belt corresponds to the *Volviflustrellaria*-free beds postulated by Brydone (*in* Brighton 1939) to occur near the base of the *mucronata* Zone. *Echinocorys* ex gr. *conica* has not been recorded, but small conical flat-based forms known from the Drift probably come from this belt by analogy with other areas. Fragmentary belemnite material from Taverham Park and elsewhere is suggestive of the moderately strongly vascularised, large elongate forms with an acute rather than mucronate apex that characterise the basal part of the *mucronata* Zone in Northern Ireland [Boheeshane $C_2$] and approximately correlative beds in Hants. These belemnites are quite distinct from the forms grouped round *B. senior* Nowak that characterise Pre-Weybourne$_3$ and above, and appear to exhibit closer affinities with the group of *B. praecursor*.

Representative locality: Taverham Park Lodge pit (?Rowe 170) [1474 1386].

**Pre-Weybourne$_2$**

*Volviflustrellaria taverensis* is abundant. *Echinocorys* ex gr.

conica is uncommon or rare; Brydone Coll. [NCM] has a small flat-based form with a markedly symmetrical lateral profile. Belemnites not uncommon (Rowe MS), but none of the Rowe material can be found; an alveolar fragment [BGS] from Taverham is suggestive of the forms discussed above under Pre-Weybourne$_1$.

Representative locality: Taverham (Rowe 186) [1616 1408].

**Pre-Weybourne$_3$**

This belt is characterised by the regular occurrence of Volviflustrellaria taverensis and thus falls within the Basal mucronata Chalk as defined by Brydone. Echinocorys conica and related forms occur throughout, but are particularly common in association with hardgrounds and/or horizons of indurated chalk. There are one or more horizons with Galeola. Other echinoids include Echinocorys subglobosa Goldfuss and Cardiotaxis heberti. Belemnites are represented by predominantly corpulent forms near Belemnitella senior, although some small lanceolate forms of uncertain affinity also occur.

Representative localities: Newfound Farm pit, Cringleford [1892 0692]; sewer excavations on opposite side of river [189 074 - 190 072]; Colney Food Centre excavations [1835 0780]; Bowthorpe Hall sewer trench [1789 0905 - 1768 0913]; Drayton [174 131 and 1801 1383].

**Pre-Weybourne$_4$**

This is a relatively barren belt of soft chalk with small burrow-form 'finger' flints and one or more horizons of yellow-stained, slightly more indurated chalk. The apparent absence of Volviflustrellaria taverensis places this belt within the Eaton Chalk by Brydone's definition. No brachiopods and only indeterminate fragments of belemnites have been observed. It is characterised by Echinocorys humilis Auctt. non Lambert, which occurs associated with the yellow chalk horizons.

Representative locality: Cringleford By-pass section [1965 0590].

**Pre-Weybourne$_5$**

This belt is characterised by a large tall conical form of *Echinocorys* with a flat and circular base and thus corresponds to Brydone's 'Eaton Chalk' as defined by Brydone (*in* Brighton 1939). It also more or less equates with Rowe's '*minor*-*bayfieldi* band' defined by the frequent occurrence of *Galerites*? *minor* Rowe MS and *Galeola papillosa basiplana* [p.20], and with the richly fossiliferous chalk from below flint Z up to about flint X of the Peake and Hancock section of the coastal succession at Weybourne. Other diagnostic echinoids are large *Echinocorys* ex gr. *conica* - this belt marking the top of the range of the *E*. *conica* group in the Norfolk *mucronata* Zone - *Cardiotaxis heberti* and *Micraster glyphus*. *Cretirhynchia lentiformis* is common. This belt equates with the *Trachyscaphites spiniger*/*Galeola papillosa basiplana* Zone of the standard Misburg and Lägerdorf successions, German Federal Republic, and thus with the *stratum typicum* of the proposed neotype 'population' (Christensen *et al*. 1975) of *Belemnitella mucronata* (Schlotheim); it is probably also the source of an unlocalised poorly preserved internal mould fragment [NCM] of *Trachyscaphites* cf. *spiniger* (Schlüter).

Representative localities: lower part of Eaton Limeworks section [208 063]; the basal beds of Howe's chalk pit, Keswick [212 048]; temporary sections for foundations on the site of the University of East Anglia [c.193 076].

## Weybourne Chalk

The Weybourne Chalk as understood here comprises the succession from the top of the local range of *Echinocorys* ex gr. *conica*, i.e. approximately flint Z of the coastal stratotype (rather than flint Z as in the original definition) up to the terminal erosion surface of the main Catton Sponge Bed. Three poorly delimited faunal belts are provisionally recognised.

### Weybourne$_1$

This is a comparatively oyster-free belt characterised by abundant *Cretirhynchia lentiformis*, common *C. woodwardi* and *Kingena pentangulata* (S. Woodward) and infrequent *Magas* sp. nov., *M.* aff. *pumilis* and *Neoliothyrina*? sp. nov. The echinoids include *Echinocorys gibba oviformis* Lambert, *E. ovata* Leske *sensu* Smiser *non* Lambert, and *Micraster glyphus*. The belemnite fauna is inadequately known, but poorly preserved material from the correlative coast section includes *Belemnitella mucronata*, *B.* '*lanceolata*' Sharpe *non* Schlotheim (p.53) and late derivatives of *B. senior*. In the higher part of this belt at Keswick the belemnites comprise exclusively *B.* '*lanceolata*'. The remaining fauna is of low diversity.

Representative localities: the upper part of Eaton Limeworks [208 063]; the upper part of Howe's chalk pit, Keswick [212 048]; and the corresponding part of the coastal stratotype extending from flint X up to an unspecified level above flint S.

### Weybourne$_2$

This belt is marked by an abundant and diverse oyster assemblage, typified by *Hyotissa* [*Lopha*] *semiplana* (J. de C. Sowerby) [Woods 1903-14, fig. 193] and a form of *Pycnodonte* (*Phygraea*) *vesicularis* (Lamark) with the umbo elevated high over the hinge-line, and a well-defined posterior wing [Woods 1913, figs. 174-9]. *Chlamys mantelliana* d'Orbigny is common, together with *Spondylus* sp. nov. [see p.61]. *Micraster* (*Isomicraster*) aff. *stolleyi* has been collected from the Eaton Golf Course pit, and abundant *M. stolleyi* and *M. glyphus* occur in the presumed correlative of this belt in the Weybourne stratotype. This faunal belt is probably the source of relatively dark-coloured and uncrushed museum specimens of *Echinocorys gibba oviformis* and *Cardiotaxis heberti* labelled 'Harford Bridges' and preserved in comparatively hard chalk. The belemnites are exclusively *Belemnitella* '*lanceolata*'. This belt is also marked by the entry of non-tuberculate *Nostoceras* (*Bostrychoceras*) sp., questionably referable to *N.* (*B*) *polyplocum* (Roemer) s.s. [i.e. Schlüter 1872, pl.33, figs. 3, 4]. *Cretirhynchia woodwardi* is common, but the apparent absence of *Cretirhynchia lentiformis* is striking.

Representative localities: Eaton Golf Course pit [2188 0576] and the corresponding part of the coastal stratotype, at least including the succession between flints Q and O, but with the lower and upper limits left undefined.

## Weybourne$_3$

In marked contrast to Weybourne$_2$, oysters, particularly *Hyotissa semiplana*, are not a significant component of this faunal belt. *Carneithyris* enters near the top together with *Cretirhynchia arcuata*; *C. woodwardi* and small narrow forms of *Magas* sp. nov. [Davidson 1852, pl.2, figs. 10-11] are relatively common. *Orbirhynchia* was reported (Brydone 1938) to characterise correlative beds on coast, i.e. to the west of Sheringham Lifeboat House. The echinoid fauna is poorly known: *Echinocorys* is uncommon with no particularly distinctive shape-variants; questionable examples of *Offaster* from 'Catton' [NCM] suggest a parallel with the occurrence of this genus in the correlative Northern Ireland succession [top Ballintoy B and basal Glenarm - see Fletcher and Wood (1978)]. The belemnites are apparently all *Belemnitella minor* Jeletzky and related forms.

The upper limit of this faunal belt coincides with the terminal erosion surface of the main Catton Sponge Bed at the top of the Weybourne Chalk. The Catton Sponge Bed has yielded a diverse assemblage of hexactinellid sponges, together with moulds of aragonite-shelled molluscs incluidng the ammonites *Nostoceras* (*Bostrychoceras*) sp. and *Menuites portlocki* (Sharpe). The main Catton Sponge Bed is overlain by an unknown thickness of Chalk with similar hard beds, considered here under the Beeston Chalk.

Representative locality: Catton Grove, lower section and lower part of upper section [2289 1094].

**Beeston Chalk (undivided)**

The Beeston Chalk is characterised by the development of 'ring flints' and by apparently laterally continuous belts of chalk rich in large fragments of Inoceramus shell. In both these respects there is a remarkable parallel with the correlative Portrush Chalk of Northern Ireland (Fletcher and Wood 1978). The ring flints increase in size and complexity upwards and in the higher part of the succession sporadic paramoudras occur. The fauna at some horizons is extraordinarily rich both in numbers and diversity, reflecting a highly favourable environment. Enhanced sea-water temperatures are suggested by the fact that ahermatypic corals - Coelosmilia granulata Duncan, C. wiltshirei Duncan and Dungulia? [Parasmilia] cylindrica (Milne Edwards and Haime) - reach their maximum size and frequency in this part of the mucronata Zone, as do the brachiopods Carneithyris carnea and Cretirhynchia norvicensis.

The Beeston Chalk fauna is characterised by a flat-based Echinocorys aff. conoidea (Peake and Hancock 1961, p.318), Cardiaster cordiformis and large Galerites vulgaris (Leske). Austinocrinus bicoronatus (Hagenow) occurs sporadically. The most distinctive brachiopods are the rhynchonellids Cretirhynchia arcuata and C. norvicensis, of which the latter commonly exhibits pale to dark purple colour markings, particularly in gerontic individuals. Carneithyris, likewise showing colour markings in some examples, exhibits a high degree of variability, and the following taxa recognised by Sahni (1929, 1958) were based on type material from Beeston Chalk localities: Carneithyris carnea, C. elongata (J. de C. Sowerby), C. [Pulchrithyris] gracilis (Sahni) and C. subovalis Sahni: Asgaard (1975) has demonstrated that these are all morphological variants of the single species *C. carnea*.

Compared with the underlying Weybourne Chalk (especially Weybourne$_2$), the apparent absence of the oyster *Hyotissa semiplana* (J. de C. Sowerby) and the form of *Pycnodonte* (*Phygraea*) with a high umbo and well-defined posterior wing is striking; the latter group is represented by a form with low umbo and poorly defined posterior wing [Woods 1913, figs. 161-167], which is probably conspecific with *Gryphaea globosa* (J. de C. Sowerby 1823, pl.392].

The belemnite assemblages are dominated by *Belemnitella* '*langei*' Auctt. *non* Jeletzky (see p. 68) and *B. minor* with subordinate examples of the giant form *B. mucronata* sensu Jeletzky (Jeletzky 1964, pl.1, figs. 4a-c). Poorly preserved glauconitised ammonite and nautiloid internal moulds are not uncommon at certain horizons which preserve fossils with an originally aragonitic shell: these include *Baculites* aff. *anceps* Lamarck, *Neancyloceras bipunctatum* (Schlüter), *Neocrioceras* (*Schlueterella*) sp. and *Cymatoceras bayfieldi* (Foord and Crick). Unlocalised specimens [e.g. BMNH C4396] of *Diplomoceras cylindraceum* exhibit the same preservation. Similarly unlocalised museum material [BGS; NCM] of *Nostoceras* (*Bostrychoceras*) is weakly tuberculate towards the lower part of the whorl, and thus contrasts with the non-tuberculate *N.* (*B.*) *polyplocum* of Weybourne$_2$; comparable forms were figured (as *Heteroceras polyplocum*) by Schlüter (1872, pl.33, fig.5; pl.34, fig.1) - see discussion in Howarth 1965, pp.372-3).

Representative localities: the rock-platform below Beeston Hill east of Sheringham [165 435] (stratotype), Caistor St. Edmunds working chalk-pit (Rowe 166) [2390 0466] and the former Mousehold, earlier Magdalen Chapel pit (Rowe 160) [236 105]. The last locality was the source of extensive material in the Rowe Coll. [BMNH].

**Paramoudra Chalk**

This subdivision is characterised by chalk with columns of giant vertical cylindrical flints up to several metres long (paramoudras) formed round the burrow *Bathichnus paramoudrae* Bromley, Schulz and Peake (see Bromley *et al*. 1975). The base is marked (on the coast) by one or more hardgrounds containing the saurian *Mosasaurus*. This presumably equates with the Lollards Pit in Norwich, from which *Mosasaurus* has been recorded.

### Paramoudra$_1$

The chalk of this belt is characterised by abundant columns of paramoudras. It is highly fossiliferous in the single extant Norwich locality - Whitlingham (Rowe 154) [2687 0766] - but the correlative coastal exposures east of West Runton are apparently comparatively barren apart from belemnites and rare *Echinocorys*. It is characterised by sporadic *Micraster ciplyensis* and *Echinocorys* ex gr. *belgica* Lambert together with the typically Beeston species *Cardiaster cordiformis*. The rich brachiopod fauna is dominated by small-sized *Carneithyris* and *Cretirhynchia* transitional between *C*. *arcuata* and *C*. *limbata* (Schlotheim). Thin-shelled large gryphaeate *Pycnodonte* occur sporadically, as does *Chlamys* cf. *denticulata* (Hagenow). *Proliserpula ampullacea* (J. Sowerby) and *Ostrea triangularis* S. Woodward are particularly common, to judge from the Rowe Coll. from Whitlingham. The belemnites include *Belemnitella* '*langei*' and *B*. '*posterior*' Kongiel (see p. 75 for discussion for the latter form).

### Paramoudra$_2$

This is composed of predominantly yellow, richly fossiliferous chalk with beds of moderately indurated chalk developed at several horizons. Paramoudras are reported, but they are not as abundant as in Paramoudra$_1$; huge anastomosing overgrown thalassinoid nodular flints are seen in extant localities. It is characterised by common

*Micraster ciplyensis*, rarer globose *M*. aff. *grimmensis* and relatively depressed, thick-tested *Echinocorys* ex gr. *belgica*; also *Cardiaster* sp. near *C*. *granulosus* and a small *Galerites* sp. The high Upper Campanian-Lower Maastrichtian marker crinoid *Austinocrinus bicoronatus* occurs regularly. Rhynchonellids include forms with Maastrichtian affinities, e.g. a wide, finely costate *Cretirhynchia* aff. *retracta* which occurs in the pre-*Porosphaera* and *Porosphaera* Beds on the coast at Sidestrand, and *C*. aff. *magna*. The *Carneithyris* are predominantly of small size. The oysters are typically large thick-shelled gryphaeate forms of *Pycnodonte* (subgenus uncertain) comparable with those of the Maastrichtian. Pectinids are represented by forms near or conspecific with the Maastrichtian *Chlamys denticulata*. The belemnites are as in Paramoudra$_1$, i.e. *Belemnitella* '*langei*' and *B*. '*posterior*'. Ammonites probably occur in the indurated beds on the basis of unlocated museum material [King and Fitch Colls, NCM], but provenance of these specimens from lower beds cannot be excluded. Collecting during the re-survey has yielded poorly preserved indeterminate baculitids. A well-preserved internal mould of *Hoploscaphites* [NCM 2173] in an intensely hard yellow chalkstone matrix comparable with hard chalk dredged from the River Yare at Bramerton Common is probably from this faunal belt or from the overlying Lower Maastrichtian.

Representative localities: Thorpe Asylum Pit (Rowe 153) [2755 0900], Thorpe Tollgate [2830 0894], Postwick Grove [2866 0801].

## Details of key sections

Peake and Hancock (1961, p.314) considered that the Norwich Chalk probably exceeded 400 ft (122m), of which only an aggregate of 180 ft (55m) was then exposed, and much of that in coast sections rather than in pits in the vicinity of Norwich itself. As a result of the re-survey an aggregate total of 76m of section has been measured and studied in detail; this includes two temporary sections [Bowthorpe Hall sewer trench and the Cringleford By-pass] and there may well be some overlap between Newfound Farm and Bowthorpe sewer. This aggregate total could be extended by excavating sections in overgrown localities, particularly Thorpe Asylum and along the south side of the Yare near Whitlingham.

These key sections can be summarised as follows, reading in downward stratigraphical order:

| locality name | Thickness (m) |
|---|---|
| Postwick Grove [2866 0801] | 2.18 |
| gap | |
| Whitlingham (Colman's pit) [2678 0766] | 4.52 |
| gap | |
| Caistor St. Edmunds [2390 0466] | 16.31 |
| gap | |
| Stoke Holy Cross [2356 0140] | 15.09 |
| Catton Grove [2289 1094] | |
| gap | |
| Eaton Golf Course pit [2188 0576] | 5.49 |
| gap | |
| Keswick [212 048] | 14.50 |
| Eaton Limeworks [208 063] | |
| gap | |

| | |
|---|---|
| Cringleford By-pass [1865 0590] | 6.93 |
| gap | |
| Newfound Farm pit, Cringleford [1892 0692] | 2.45 |
| gap | |
| Bowthorpe sewer trench [1789 0905] | 5.33 |
| gap | |
| Drayton [1801 1383] | 3.66 |
| | 76.46 |

**DRAYTON** [174 131] Rowe loc. 152. BGS: HBW 307?; CJW 3795-3828; Leeder Coll. [NCM], Peake Coll.

Rowe MS: "Section about 12 ft [3.6m]. One flint course apparently level and continuous stretches across the pit. Flints of usual type and many of considerable size stained with iron and manganese".

He recorded a small fauna, none of which has been located in the BMNH: "*Echinocorys* large 4 c[common]; *B. mucro* c large; *R. plicatilis* 1; *R. limbata* 2; *O. hippopodium* 4; *Crania costata* 6". There is, however, a magnificent bivalved specimen of *Gryphaeostrea canaliculata* (J. Sowerby) [BMNH L81160] in the Rowe collection from this locality.

The section has much degraded in recent years, and is now extensively tufa-encrusted. The owners do not normally permit access to the pit. The section includes two irregular flint courses, the upper one being either paired or a flint zone and locally caught up in the cryoturbation zone; the lower is single and contains sporadic *Volviflustrellaria taverensis*. Belemnites are relatively common below the upper flint. Mr. N.B. Peake (pers.comm.) noted that *Echinocorys conica* could formerly be collected in considerable numbers; of these abut 50 per cent were flint-infilled and very well preserved, most of them having come from the second (lower) flint course. A 3m sloped trial hole in the base of the pit yielded *Galeola* between *papillosa* and *basiplana* and many *Belemnitella* ex gr. *senior*.

HBW 307 is a typical Drayton type flint-infilled *Echinocorys conica* which probably came from this locality, although it is possible that it may have come from the former pit at [1885 1350], which more or less equates with the Bowthorpe Hall sewer section.

The limited fauna collected by the author includes: *Porosphaera nuciformis*, *Dungulia*? ['*Parasmilia*'] *cylindrica*, *Volviflustrellaria taverensis*, *Ditrupa* sp., *Glomerula gordialis*, *Ancistrocrania parisiensis* (Defrance), *Cretirhynchia lentiformis*, *Belemnitella* ex gr. *senior*.

The Leeder Coll. [NCM] includes 20 comparatively poorly preserved and corroded *B*. ex gr. *senior*, of which 11 came from between the two flint courses and 8 from below the lower course.

Drayton falls at or near the Basal *mucronata* - Eaton boundary according to Peake and Hancock (1970, p.339D), although the occurrence of *Volviflustrellaria taverensis* must by definition place it in the former division. Compared with Taverham, *V*. *taverensis* is less common while *E*. *conica* is relatively abundant, so that its stratigraphical position lies somewhere in the upper part of the *Volviflustrellaria* belt recognised by Brydone, i.e. Pre-Weybourne$_3$ of this account.

**BOWTHORPE HALL** sewer trench section [1789 0905 - 1786 0913]
BGS: CJW 7404-7424

During August 1975 a 3m deep sewer trench section was cut alongside the boundary wall of Bowthorpe Hall. When this was examined, the chalk section had already been obscured by sheet piling and it was not possible to make detailed measurements. Spoil heaps from this trench included blocks of creamy-white and also yellow indurated chalk, but most of the chalk was relatively soft and white with scattered flattened thalassinoid flints. A rich echinoid fauna was collected by the author from the spoil comprising 14 small to medium-sized Echinocorys conica (of which 2 were flint-infilled), 2 E. subglobosa and 1 poor chalk internal mould of Cardiotaxis heberti. The tests are slightly pink coloured with superficial limonitic staining, and most carry a diverse adnate epifauna. Both the E. subglobosa are incomplete and were broken prior to fossilisation; the majority of the E. conica are complete and those that are filled with hard yellow chalk or flint are virtually undeformed. One flint-infilled specimen [CJW 7407] retains small spatulate spines on the adoral surface. The adnate fauna is particularly diverse and includes Porosphaera sessilis, Sclerostyla macropus, Vepreculina tuberculifera (Nielsen), Crania aff. craniolaris Linne, Atreta nilssoni, Gyropleura inaequirostrata and Pycnodonte sp; membranimorph bryozoan colonies occur commonly, and of note is a well-preserved Callopora lyra (Hagenow) [CJW 7414]. Many of the adnates, particularly the serpulids, are somewhat abraded and this also applies to some of the tests themselves, which clearly must have rolled around as pebbles on the sea-floor.

Some weeks after this section was examined the trench was extended across the road, at which point it turned through a right-angle and continued for a further 2m; Mr. N.B. Peake was able to see and measure a clear section, details of which have been kindly made available for this account (Fig. 1). A rusty-brown soft 'hardground' (lower hardground) with Echinocorys conica was present near the base of the section. The higher 'hardground' had no apparent erosion surface, and consisted of a band with intensely indurated lumps of chalk. The surface of these lumps and some planes within them were heavily coated with limonite which was presumably pseudomorphing pyrite. Several E. conica were collected in situ [Peake and NCM], and many of these are filled with chalk as hard as some of the harder lumps within the 'hardground' - and in fact many constitute some of the lumps themselves. It seems certain that this 'hardground' is the source of most of the undeformed echinoids in the collection made from spoil heaps beside Bowthorpe Hall. In addition to the echinoids, a number of Belemnitella ex gr. senior have been collected loose [NCM], but no other macrofauna has been noted. The upper part of the section is reported to be apparently devoid of E. conica.

The sewer trench was situated close to Rowe loc. 177 [1802 0903], and the two sections are probably stratigraphically equivalent. Rowe (MS) placed the latter locality on the 'Cley Line' on the basis of the occurrence of Volvolunulites - i.e. Volviflustrellaria taverensis - but prolonged search has failed to find this bryozoan in the sewer section, nor was it recorded at the BGS collecting locality 183 m west of Bowthorpe Hall at [1760 0908] (see list, p.79). From a consideration of relative levels - given that the Chalk surface at the site of the measured Bowthorpe section is approximately 23m OD - Bowthorpe sewer is stratigraphically above Drayton, but may equate with the section obscured beneath the talus at Cringleford (Newfound Farm pit) which would thus have its floor formed by the upper hardground. Similarly, the Colney Food Centre hardground (p.80) would then fit in between Drayton and the Bowthorpe sewer section.

**CRINGLEFORD** (Newfound Farm pit): [1892 0692]. BGS: CJW 3731-3739; 7392-7398

A small section on the west side of this degraded but still fairly open pit exposes a semi-continuous, large, flattened, up to 25 cm, grey-skinned thalassinoid flint, below which 1.85m of flintless chalk were proved by digging. The flint incorporates incomplete Echinocorys conica and is probably the source of loose flint-infilled specimens. Immediately above the flint the chalk contains ferruginous sponge meshworks and yielded Chlamys sp., Spondylus dutempleanus, chalk-infilled *E. conica* and three chalk internal moulds of *Galeola papillosa basiplana*; *Galerites* is also mentioned in the original field-notes, but the specimens were apparently not collected. A second flint course comprising a scatter zone of small flints is seen in the cryoturbated top of the section, some 0.60m above the main flint. The only belemnites were several *Belemnitella* ex gr. *senior*, including one specimen very close to the holotype of *B. senior* s.s., all of which came from immediately below the main flint. The possible correlation of this pit with the Bowthorpe Hall sewer section has already been discussed on a basis of relative levels; furthermore the pattern of flint distribution at Newfound Farm is remarkably similar to the upper part of the sewer section, although the Newfound *Echinocorys conica-Galeola* horizon is apparently not represented at Bowthorpe. This pit is presumably the one from which Brydone (1938, p.16) recorded *Volviflustrellaria taverensis*, which would automatically place it into the pre-Eaton Chalk *mucronata* Zone, i.e. into the Basal *mucronata* Chalk as strictly defined. This point is considered further below (p.52) in the context of the type locality of the Eaton Chalk.

**CRINGLEFORD BY-PASS** road-cutting section [1965 0590]

Up to 8.5m of chalk exposed during 1974 in cuttings to the north-east and south-west of the Colney Lane bridge-crossing (Fig. 2). The lower part of the 6.9m section given here was measured in the deep excavation for the bridge foundations, details of the upper part being supplied by Mr. N.B. Peake from examination of the top of the cutting. The most important marker-horizon is a massive tabulate (up to 20 cm) lint band of which many of the individual flints are bent in a istinctive manner; this flint is overlain by a bed of yellow chalk ith harder lumps which forms a conspicuous yellow band in the sides of the cutting. From this level Mr. Peake has collected several Echinocorys humilis Auctt non Lambert (1903, pl.3, figs.10-11), and he has also found one or more specimens at the base of the section. The remainder of the section is in relatively soft chalk characterised by finger-like burrow-form flints. The whole section, with the exception of the E. humilis horizon, is apparently remarkably barren, although some belemnite fragments were noted just above the burrow-form flint 0.90m below this. No examples of E. conica, even fragments, have been observed in this section, although Mr. B. McWilliams collected one [NCM] from the spoil from a sewer inspection shaft in the adjoining low-lying ground at approximately [1996 0611] - i.e. at a level which presumably corresponds to the top of the Newfound Farm pit. The question of partial overlap between the Cringleford By-pass section and the base of Eaton Limeworks remains unresolved, but the balance of evidence suggests that an Echinocorys conica-free belt [Pre-$\text{Weybourne}_4$] characterised by one or more horizons with E. humilis - i.e. the Cringleford By-pass section - intervenes between the upper part of the main conica belt [Pre-$\text{Weybourne}_3$] - i.e. Newfound Farm - and the hard beds with topmost 'Eaton; [Pre-$\text{Weybourne}_5$] Echinocorys assemblages, including the giant conical extreme variant of the conica lineage, which are present towards the base of the Eaton Limeworks section.

**EATON LIMEWORKS**; Rowe's 'Cunnell's Pit, Newmarket Road' or Eaton Chalkpit [208 063]. Rowe loc. 185, Rowe Coll. [BMNH]; Brydone and Leeder Colls. [NCM]; BGS: CP 241-278; Hr 463-465; Ya 3121-3122; CJW 3686-3730

This pit, a Nature Conservancy Council SSSI, is the stratotype for the Eaton Chalk, and the type-locality for Galeola sp. nov? (Brighton 1939), now referred to G. papillosa basiplana. Rowe MS provides the following information [taken from several different pages]:

> "Large section with working kiln and many adits. Chalk as blocky as it ever is at Norwich but much drier and better weathered than usual. Flints usually black and with no cortices...... Men give the pit as 60 ft deep and say that they strike the water at that level. Foreman is familiar with Conulus and says that it is found at bottom of pit. The small Echinocorys he knocked out of a flint. Base of pit covered with talus save in caves, and there too moss-grown to work. There was one flint cast of a very pointed nature and larger than, but much resembling the Tharston variety (probably from gravels)..... Echinocorys bayfieldi and Conulus, the latter small, as at 155 and 156, found at base of pit, there being here about 40 ft of chalk..... The hard red gastropod bed is here found at lowest level of pit in 2 or 3 bands rarely a foot thick, and separated by the usual soft chalk. There is a bed of soft chalk of worm-eaten appearance 10" thick which readily washes up and is fairly rich in fossils. This is about 6 ft from base of pit but very local and only in two caves at NE corner of pit".

Rowe also gives an extensive faunal list from which it is significant that he notes "T.(erebratula) carnea" [i.e. Neoliothyrina? sp. nov?] as being "very rare and small".

Rowe's observations, believed to have been made circa 1911, can be confirmed by an excellent photograph of the pit taken in 1912. This photograph [NCM archives] shows two sides of a large pit exposing clean faces of chalk with numerous flint courses, overlain by Norwich Crag. To judge from a figure 6 ft [1.8m] tall in another photograph, it appears likely that both the total depth of 60 ft [18.3m] for the pit and the thickness of 40 ft [12.2m] for the exposed Chalk given by Rowe are reasonably accurate. The total thickness of Chalk agrees well with that which can be measured today (see below) and the photograph is sufficiently clear for the stratigraphy to be interpreted. Five tunnel entrances of various dimensions can be seen, and it is interesting to note that, in three cases, the tunnel roof is formed by one or other of the two most conspicuous flint courses. The second photograph, and associated sketches, reveals the existence of a narrow pipe extending vertically through the Chalk on the Newmarket Road side of the pit, the pipe opening upwards into a broad funnelshaped structure beneath the overlying deposits. It is clear from the photographs that the sides of the pit were vertical, and consequently the only in situ collecting possible would have been from the base of the succession, i.e. where Rowe collected his minor-bayfieldi band.

The section available to Rowe and others was almost completely obscured by the late 1960s apart from exposures by the only surviving tunnel entrance (Hornby et al. 1973). This entrance was deliberately blocked in 1969, but was re-exposed and enlarged in 1971-72, so that it is now possible to gain access to two of the underground tunnels.

During 1966-67, Dr. Leeder (MS) made detailed measurements of the section inside the tunnel entrance cave and collected fossils systematically with reference to lettered flint bands. A modified version of this section was given by Goff (in Hornby et al. ibid., fig. 1), together with a short description of the distribution of the fossils taken largely from Dr. Leeder's notes and collections. The published section includes three beds of hardened chalk termed the lower, middle and upper hardgrounds [sic]. These 'hardgrounds' were not formally recognised by Dr. Leeder, and there are also significant differences in the published measurements of intervals between certain flint bands compared with those in his MS. This section has been re-measured for this paper using Dr. Leeder's notation for the flint bands (Fig. 3). Close examination of the 'hardgrounds' was not possible due to the inadequate illumination inside the tunnel, but it appears probable that the use of the term hardground is inappropriate, the so-called hardgrounds being no more than irregularly bounded zones of patchily indurated and iron-stained chalk associated with breaks in sedimentation. There is no sign, at any horizon, of the hardened and/or mineralised bored surface, which would denote a true hardground. In particular, Goff's 'middle hardground' was not observed, although an irregular, thin, (less than 10 cm) band of harder chalk was noted by Leeder on his MS section below flint B.

When the Eaton section was remeasured (1975), it was clear that it must overlap to some extent with the section at Keswick. Recently (1987), Mr. A. Pitchford (Liverpool University) has examined both sections, in particular a deeper section at Keswick than was available to the author. He is now able to show (Pitchford, in prep.), both on a consideration of the relative OD levels of the two pits, and on the types and spacing of the flint courses, that there is a close correlation between the two sections, with Eaton extending slightly lower and Keswick some 2m higher respectively. The section of Keswick, given here (Fig.4, p.111) is incomplete, and corresponds only to the upper half of the Eaton, starting at about flint B of Leeder's notation.

The author's collection, comprising mainly brachiopods, small pink *Pycnodonte* (*Phygrea*) sp. and belemnites, was made from a small exposure some distance from the section in the tunnel, and it is not certain how the two sections correlate. The information from the Leeder Coll. can be summarised as follows:

Below Flint A: no fossils recorded.

A-B interval: Leeder notes that belemnites and *Echinocorys* are common in the hard yellowish chalk around the A1 flints (i.e. Goff's 'lower hardground'). At an unspecified level within this interval he collected a flint-infilled specimen of the giant conical variant of *Echinocorys* ex gr. *conica* [EL3]. Also from this level are 3 belemnites and 6 *Cretirhynchia* *lentiformis*.

B-C interval: belemnites abundant (35); also small brachiopods comprising *Magas* sp. nov (1), small *Neoliothyrina*? sp. nov? [*Carneithyris* in Goff's list] (2) and dominant *Cretirhynchia* *lentiformis* (37). Goff (*ibid*., p.8) recorded small bun-shaped *Galerites* - i.e Rowe's '*Conulus* *minor*' - from the 'upper hardground' at the top of this interval, together with a conical form of *Echinocorys*. The latter may be the specimen EL3 noted above from the A-B interval, which Leeder on a separate correlation diagram [MS] and [*in litt*: 1975] recorded against Goff's upper hardground. There is further doubt regarding the *Galerites* in that the only recently collected specimens from this locality in NCM are associated with a label giving the horizon as 'middle hardground'. Leeder may also have collected a number of Galerites from the upper hardground since these are recorded on his correlation diagram, but the whereabouts of these are not known.

C-D interval: 1 belemnite; C. lentiformis (3).

D-E interval: 1 belemnite; C. lentiformis (8), Kingena pentangulata [K. lima in Goff's list] (1).

E-F interval: 4 belemnites; K. pentangulata (4), M. sp. nov. (1), Neoliothyrina? sp. nov?, C. lentiformis (20). The brachiopods, notably the Cretirhynchia and Kingena, tend to occur in clumps.

F-G interval: 3 belemnites; C. lentiformis (2).

An important record from this locality in the Rowe Coll. is a rostrum of a Hagenowia sp. [BMNH E40178] which Dr. A.S. Gale [pers. comm.] has identified as H. aff. elongata (Nielsen): this form is presumably an Upper Campanian precursor of the high Lower Maastrichtian species H. elongata. Comparable rostra from an even higher position in the Upper Campanian [Beeston Chalk] have been previously recorded as late forms of H. rostrata (Forbes) - see Wright and Wright (1949, fig. 10); Ernst and Schulz (1971, Abb.2).

Also in the Rowe Coll. is a specimen of the large limid Plagiostoma marrotianum (d'Orbigny), which in both England and Northern Ireland appears to be restricted to the lower part of the mucronata Zone, i.e. pre-Catton Sponge Bed fauna. Other Norwich records are from Keswick [Weybourne$_2$] and Catton Grove [presumably Weybourne$_2$ or Weybourne$_3$].

The CP [Chatwin] collection includes three unlocalised small Galerites and six Galeola papillosa basiplana. The latter are all preserved in a relatively soft chalk and presumably did not come from any of the 'hardgrounds'; one of these [CP 272] was figured by Ernst (1971, Abb.23, fig.6). Chatwin collected five Echinocorys, among which are a typical E. humilis from 5 ft [1.5m] above the pit floor, and two unlocated E. subglobosa with a marked pyramidate apex.

Hayward (1940, pp.82, 87) grouped these five specimens with a further 19 specimens in the Brydone Coll. [NCM] and used them in a semi-statistical analysis of a supposed Eaton 'population', presumably unaware of the very much larger Rowe collection from 'Cunnell's pit, Newmarket Road'.

It is clear from Rowe's notes that the minor-bayfieldi band was situated near the base of the pit, presumably near the level at which he recorded the 'hard red gastropod bed' comprising two or three bands rarely 1 ft (0.3m) thick, separated by soft chalk. The contemporary photograph shows that the section available to him was comparable to that exposed today in and above the tunnel entrance. On the basis of Leeder's collecting, it would appear likely that the 'minor-bayfieldi band' corresponded to the base of the exposed succession up to the 'upper hardground' below flint C, this being also the sequence that yielded Brydone's distinctive Eaton fauna [Pre-Weybourne$_5$ of this account], characterised by Galeola papillosa basiplana and the giant form of Echinocorys conica.

Above flint C, there is a significant faunal change, with a marked reduction in the abundance of belemnites and echinoids. As discussed above (pp.27, 33), it is possible that this faunal change marks the junction between the pre-Weybourne Chalk and the Weybourne Chalk, with the base of the latter being taken at the equivalent of flint X of the coast section rather than flint Z as hitherto. This would place the upper two-thirds of the Eaton succession into the basal part of the Weybourne Chalk, an assignment substantiated by the general Weybourne aspect of the belemnites [Belemnitella 'lanceolata Sharpe non Schlotheim'] and the occurrence of a narrow-based variant of Echinocorys gibba [Leeder Coll.] at the top of an adjacent section. Although it is unlikely that flint bands developed on the coast section will also be recognisable at Norwich, there are sufficient similarities between the type and pattern of spacing of flints D to G inclusive of the Eaton section and the flint W-T sequence of the Weybourne stratotype to suggest a broad correlation (A. Pitchford, pers. comm. and in prep.). Given that (sensu Brydone) the Newfound Farm pit belongs to the pre-Eaton Chalk succession, this means that his Eaton Chalk becomes restricted to the Cringleford By-pass section and the base of the Eaton stratotype - and thus effectively to the local observed range of Echinocorys humilis.

**KESWICK CHALKPIT** (Williams Howes & Son, formerly Leicester Lime Co Ltd) [212 048]. Peake loc. 294. Goff Coll., Leeder Coll. [NCM]; BGS: CJW 3615-3673; 5156-5157; 5189-5197; 5244-5255; 7347-7387.

This pit, formerly worked intermittently, had become progressively degraded until it was acquired by Howes in 1974. Since then, some of the main faces have been worked back, and deep cuts have been made below the water table. A maximum of 9.44m was measured by combining the sections on the northern and southern faces but, since there are significant differences between these two sections, they are both figured here (Fig. 4a and b). In the lower part of the succession, the flints tend to occur as scatter zones rather than in distinct courses, and it is therefore difficult to number them in a consistent manner. The main difference between the two sections lies in the fact that the northern section is marked more flinty, notably at the level of flints 8 and 9 where there is a local development of a black $MnO_2$-stained horizon and a blocky chalk with moulds of aragonitic molluscs, and also in the middle of the section where flint 12 becomes locally as well developed as flint 11.

As noted previously, Mr. A. Pitchford has recently (1986-87) examined deep cuts which temporarily exposed a succession deeper than that recorded by the author. He has convincingly demonstrated (pers.

comm. and in prep.) that these lowest beds broadly correlate with the lowest beds of the Eaton section, i.e. the upper part of the 'Eaton Chalk', or Pre-Weybourne Chalk$_5$ of this account. It is noteworthy that the supposed hardgrounds found at Eaton do not appear to be developed at Keswick. The succession discussed in this paper starts at about flint D of Eaton, and thus falls entirely within the Weybourne Chalk.

The Weybourne Chalk at Keswick is richly fossiliferous up to the level of the semi-continuous flint 11, the most conspicuous and characteristic fossils being abundant *Cretirhynchia lentiformis* - which can occur in clumps as in the correlative beds at Eaton - and smooth, poorly vascularised lanceolate belemnites with a pointed rather than mucronate apex. These belemnites can be most conveniently referred to *Belemnitella* '*lanceolata* Sharpe *non* Schlotheim'[1], - the type material of which (Sharpe 1853, pl.1, figs.4-6) came from the 'Upper Chalk near Norwich', and almost certainly from the stratigraphical equivalent of Keswick. Many of the belemnites are partially silicified and exhibit beekite rings; extensive clionid sponge borings occur commonly.

The lowest part of the succession seen by the author up to the level of flint 7 was exposed only in the walls of the canal cut beside the north face. The bottom flinty zone (5) comprises irregular and markedly carious flints which are relatively poorly silicified. The overlying flint 6 is a massive tabulate silicified fill of an anastomosing *Thalassinoides* burrow system, and then formed a distinct 'floor' at the base of the deepest sections on the south side of the pit. In general character and presumed stratigraphical position it resembles flint W of the Weybourne stratotype succession. This level has yielded several juvenile belemnites, a crushed *Cretirhynchia norvicensis* and a *Micraster* aff. *glyphus*. At the level of flint 7 an isolated example of *C*. *lentiformis* was collected, this being the lowest observed occurrence, together with further juvenile belemnites. *C*. *lentiformis* sets in in strength in the spongiferous blocky chalk locally developed immediately underlying flint 9. This slightly hardened chalk exhibits some limonitic staining and is probably weakly phosphatised, having yielded poorly preserved and distorted moulds of a haploid coral (*Coelosmilia*?) and aragonitic molluscs including an unidentified heterodont bivalve. This bed terminates in a hardened omission surface beneath the flint. Fossils are relatively common in the immediately overlying chalk, and include *Proliserpula* *ampullacea*, *C*. *lentiformis* (common), *Kingena* *pentangulata*, *Plicatula* '*hantoniensis*' Brydone and belemnites. This same assemblage occurs scattered throughout the flint 9-10 interval. Apart from the *Micraster* aff. *glyphus*, the apparent lack of echinoids and the low diversity of the fauna up to this level are particularly striking, presumably reflecting a semi-fluid bottom environment.

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[1] Contrary to Jeletzky's observations (1948), this distinctive Norwich low *mucronata* Zone form - also figured from the *mucronata* Zone of the Ukraine by Nikitin (1958, pl.7, figs.1-5) - is *not* conspecific with *Belemnitella praecursor* Stolley from the Lower Campanian but presumably belongs to the main Upper Campanian *B. mucronata* complex, although its precise taxonomic position remains unclear.

A change is seen at the level of flint 10 [= flint F of Eaton] with the incoming of medium-sized flat-based *Echinocorys* - *E.ovata* Leske *sensu* Smiser (1935) *non* Lambert - and *Cretirhynchia* *woodwardi*. Some of the echinoids in this part of the succession are filled with relatively hard chalk and are consequently undeformed. One specimen exhibits a number of adnate *Bipygmaeus*? *accumulata*, the serpulid which Brydone took to be characteristic of his 'Harford Chalk'. The chalk of the flint 10-11 interval is very rich in Cretirhynchia lentiformis, particularly at circa 1m and 1.5m below the top. Other small brachiopods include Magas sp. nov and M.sp. ?aff. pumilis J.Sowerby, with sporadic examples of Cretirhynchia woodwardi at the level of flint 11 [= flint G of Eaton]. The upper part of the interval contains Echinocorys, but no determinable uncrushed examples have been collected. Loose specimens collected from this general part of the succession include the distinctive depressed forms of E. gibba oviformis Lambert, and there are numerous examples in the Peake collection. Large and medium-sized guards of Belemnitella 'lanceolata' are concentrated at circa 30 cm below flint 11 on the south face, but this relative concentration was not observed in the northern part of the pit.

The succession above flint 11 can be examined conveniently only on the upper level of the south face, and even there it is affected by cryoturbation and frost-wedging with well-developed frost festooning being superbly displayed at the top of the section. These top beds are apparently relatively barren, although they are difficult to collect from and the few fossils noted may not be representative. Apart from a single C. lentiformis and an undiagnostic Belemnitella 75 cm above flint 11, the only other fossils recorded are incomplete crushed Echinocorys in the cryoturbation zone above flint 14, approximately at the horizon where Mr. A. Pitchford (pers. comm) has recently collected several associated specimens of Echinocorys.

Attention must be drawn to the distinctive sequence of flint types in the upper part of the succession, comprising (excluding the irregularly developed flint 12) the semi-continuous nodular flint 11, the irregular carious flint 13 and the scattered smooth lenticular flint 14. This sequence, combined with the large and relatively barren interval between flints 11 and 13, should be easily recognisable elsewhere and useful in local correlation.

Peake and Hancock (1970, p.339E) stated that Keswick lay near the middle of the Weybourne Chalk, with its echinoid fauna corresponding closely with that at about flint P of the stratotype. Since it is now known that the higher part of the Keswick section correlates broadly with the lower part of the Weybourne stratotype succession, this earlier interpretation needs to be re-assessed. Mr. A. Pitchford has recently studied the sequence of flint types in the Weybourne section and has made a quantitative analysis of the distribution of the macrofaunas. He considers (pers. comm. and in prep.) that flint 11 [flint G of Eaton] compares well, and may equate with, the equally strongly developed flint T of the stratotype. On this basis, the Keswick succession could extend up to about the horizon of flint R of the stratotype, but not as high as flint P.

The Weybourne Chalk of Keswick is characterised by sparse oysters and abundant *Cretirhynchia lentiformis* and thus falls into Weybourne$_1$ of the classification used here. It contrasts with the oyster-rich chalk of the Eaton Golf Course pit (Weybourne$_2$), in which *C. lentiformis* has not been observed. From a consideration of the regional dip and the relative OD levels of the two localities, Mr. Pitchford (pers. comm) considers that only a small thickness of unexposed succession, perhaps of the order of 2m, may separate them.

Neither Rowe nor Brydone collected from this pit, and the Goff and Leeder collections do not provide any useful supplementary information. Three unlocalised museum specimens are, however, worthy of note: a large *Plagiostoma marrotianum* [BMNH: LL27667]; a small *Salenia heberti* Cotteau [NCM, ex P. Cambridge Coll.]; and a group of 6 *Galeola* sp. in a flint [SM: B85394-5].

**HARFORD BRIDGES** (Hartford Bridge in 19th century references) Rowe locs. 161 and 162

This is one of the classic collecting localities for Norwich Chalk fossils and is the source of much museum material including type and figured specimens. The name of the locality is confusing, since the group of pits collectively known as Harford Bridges is situated on rising ground immediately to the north of an area known as Harford Hills and not in the bottom of the river valley. This confusion led Peake and Hancock (1961, p.336) to locate the pits incorrectly on the east side of the Ipswich Road at [221 057] rather than to the west of this road.

From the 6-inch map it can be seen that Harford Bridges is a complex of pits of varying size and antiquity. Rowe distinguished two pits in his collecting, namely Pearce's pit (no.161) for which he used the symbol HB', and Porter's pit (no.162) with the symbol HB". Unfortunately, despite the fact that both these pits were probably worked up to about forty years ago, and possibly even more recently, there is considerable doubt regarding their exact position within the complex. Mr. Chatwin's notebook (circa 1925), which includes information supplied by Rowe, states simply that "Porter's Pit is first on R(ight) ... Pear(ce)'s Pit (is) a little further on on R(ight)". On this basis it might be assumed that Porter's is the well-defined pit shown on the 6-inch map at [2203 0564]. More recently (1948), Mr. S.W. Hester of the Geological Survey collected from the Harford Bridges pits (which were then abandoned) and sketched the position of two of them in his notebook [BGS archives]. His locality I appears to correspond to the postulated position for Porter's pit, tending to confirm the assumption made above; his locality II, however, is clearly the pit at [2188 0576] on the edge of the Eaton Golf Course, which is itself the north-west prolongation of the large pit shown on the 6-inch map to the north of the limeworks. The question is whether this pit is Pearce's, or whether Pearce's was situated at [2200 0569] - i.e. "a little further on on R(ight)" from Porter's - where there is a degraded and tufa-encrusted face with an adit. The balance of the information points to the large pit north of the limeworks as having been Pearce's, but it cannot be definitely stated that the pit by the golf course - which occupies a relatively high topographical and stratigraphical level within the complex - equates exactly with the horizons collected from by Rowe. The question is therefore left open, and to avoid further confusion the pit by the golf course will be referred to as the Eaton Golf Course pit rather than Harford Bridges.

**HARFORD BRIDGES** (Pearce's pit): Rowe loc. 161. Rowe Coll; [BMNH]
BGS: CP150-166

Rowe's field notebook provides an extensive faunal list from which it is worth noting that he recorded Galeola [the small Echinocorys], also that Rhynchonella lentiformis was common, while Terebratula carnea was rare and mostly small. The common occurrence of Cretirhynchia lentiformis places this locality in the lower part of the Weybourne Chalk, i.e. Weybourne$_1$, and demonstrates that Rowe could not have been collecting from the same stratigraphical level as in the Golf Course pit, where this brachiopod has not been observed. It is possible, however, that beds with C. lentiformis are present in the latter locality but below the top of the talus (see p.61). Chatwin's collecting from Pearce's, however, also includes C. lentiformis (six specimens) together with small Pycnodonte (Phygraea) vesicularis and a Metopaster marginal.

**HARFORD BRIDGES** (Porter's pit) Rowe loc. 162. Rowe Coll. [BMNH]
BGS: CP 142-149; presumably Hr 455

Rowe's field notebook again provides an extensive faunal list, but R. lentiformis is not included (although it is included in a detailed faunal list in Rowe MSS). Hester's notebook shows up to 15 ft (4.5m) of much weathered chalk (overlain by Norwich Crag) with a prominent flint band circa 6 ft (1.8m) from the top). Chatwin, who presumably collected at a time when the face was less degraded, found Nostoceras (Bostrychoceras) polyplocum 8 ft (2.4m) up from the floor together with Ostrea triangularis; small Pycnodonte (Phygraea) occurred 3 ft (0.9m) lower. The occurrence of Nostoceras at this level is of interest and suggests an approximate correlation with the Golf Course pit, which likewise appears to be in the upper part of the Weybourne Chalk on the apparent absence of Cretirhynchia lentiformis.

Tufa-encrusted face with adit at [2200 0569] BGS: CJW 3561-3569.

For section see Fig. 5. This was once a very deep pit, but the lower two-thirds of the section are obscured by talus. The limited fauna, comprising small Pycnodonte (Phygraea) and indeterminate Belemnitella, is stratigraphically inconclusive.

**HARFORD BRIDGES:** exact locality unspecified.

A representative collection of fossils was made by H.B. Woodward in 1876-7 in connection with the 1st Edition of the Norwich Memoir. This material includes the coral Coelosmilia cf. laxa and the paratype of Sahni's terebratulid taxon Pulchrithyris (later Carneithyris) gracilis, which is now placed in the synomy of Carneithyris carnea (see Asgaard 1975, p.332). Also included is a large depressed Micraster glyphus which is suggestive of a low Weybourne Chalk provenance. Given that the Sahni brachiopod paratype probably came from a relatively high level in the Weybourne Chalk [Weybourne$_3$] it seems likely that the Woodward collection from this locality may span a considerable stratigraphical range.

**HARFORD BRIDGES:** exact locality unspecified.

A considerable amount of material was collected by Brydone [mainly NCM; also BGS: Ya 3090-3118] in the period following Rowe. This material comprises serpulids, and large echinoids of which many have an extensive adnate epifauna. The NCM *Echinocorys* from this locality were studied by Hayward (1940), who figured (*ibid*., pl.3) what he considered to be a typical shape-variant; the smaller suite in the BGS collection includes a number of extreme depressed variants of *E. gibba oviformis* with almost ellipsoidal transverse section. The NCM Brydone collection also includes several *Cardiotaxis heberti*.

**EATON GOLF COURSE PIT.** [2188 0576]. BGS: CJW 3570-3614; 5150-5155; 5504-5510; 7388-7489.

This pit must formerly have been relatively deep, but the section available to the author was only 5.5m (see Fig. 6). The flints have been given a temporary alphabetic notation for ease of reference. Flint J has so far been seen only in a trench cut into the talus, and no diagnostic fauna was collected from this level apart from an isolated valve of *Magas* sp. Flint K is a scattered, massive nodular flint, up to 25 cm thick, immediately overlying a richly fossiliferous bed of somewhat blocky chalk containing poorly preserved moulds of aragonitic molluscs. The fauna of this latter bed includes all the oysters known from the pre-Catton Sponge Bed *mucronata* Zone succession - i.e. *Hyotissa semiplana*, *Margostrea alaeformis* (S. Woodward), the small Weybourne *Pycnodonte* (*Phygraea*) *vesicularis*, *P*. (*Pycnodonte?*) sp. and *Ostrea triangularis* - with the exception of *Gryphaeostrea canaliculata*, of which a superb specimen from Pearce's pit [Rowe Coll. BMNH] was figured by Woods (1913, pl.56, fig. 14). It is probably from this or a comparable horizon that many of the fine oysters, notably *Hyotissa semiplana*, for which Harford Bridges was famous, were extracted in the days of hand-working. This bed has also yielded a depressed *Micraster* (*Isomicraster*) aff. *stolleyi* and a non-tuberculate *Nostoceras* (*Bostrychoceras*) which may be *N*. (*B*.) *polyplocum* s.s, in addition to *Coelosmilia* sp., *Cretirhynchia norvicensis*, *C*. *woodwardi*, *Neoliothyrina obesa*, *Chlamys mantelliana*, *Inoceramus* ex gr. *regularis/balticus*, *Plicatula* sp. [?=free-growing adult stage of *Atreta nilssoni*], *Spondylus* sp. nov. [*S*. *spinosus* var. *aequalis* Hebert (nom. nud.): see Zavarei 1973, p.15, fig. 9], *Arcoscalpellum maximum* and *Brachylepas fallax*. Belemnites from this and other horizons can be referred to *Belemnitella* of 'Keswick type', i.e. *B*. '*lanceolata* Sharpe *non* Schlotheim' (see p.53).

Small *Pycnodonte* (*Phygraea*) *vesicularis* occur commonly at and just below the level of flint L associated with *Cretirhynchia norvicensis*, *C*. *woodwardi*, *Kingena pentangulata* and belemnites; the higher beds have not yielded any fauna.

The exposed Eaton Golf Course pit succession can be characterised as being rich in pink oysters but (probably) lacking *Cretirhynchia lentiformis*. The types of flints and their spacing is remarkably similar to that seen in the lower part of Catton Grove (see section, Fig. 7) but consideration of the relative positions and topographic levels of the two localities precludes a correlation, as does the absence of *Carneithyris carnea* and *Belemnitella minor* from the level of Flint M in the pit under consideration.

**CATTON GROVE** (Campling's pit). [2289 1094].

Brydone, Goff and Leeder colls [NCM]; BGS: Ya 3085-3089; Zm 9998-9999; CJW 3512-3560; 5064-5081; 5403; 7425-7426

This key locality exposes a section across the Weybourne-Beeston junction, and has been designated an SSSI on account of it being the stratotype of the Catton Sponge Bed. Peake and Hancock (1961, fig. 6) recorded a total thickness of 37 ft (11.28m) and noted that 22 ft

(6.7m) were previous visible below this but that the deepest part of the section had had to be filled in because of flooding (which occurred when a continuous tabular flint forming the pit floor was broken through). This flint could possibly have been the equivalent of flint T of the Weybourne Chalk stratotype. In 1969 all but the lowest 3.28m of the published section was visible but since then the pit has rapidly degraded and has become obscured by accumulating rubbish. Eventually the whole pit will be filled in and levelled to provide building land, leaving only the uppermost section which includes the Catton Sponge Bed at its base - and even this reference section will be deliberately buried to protect it from excessive erosion by geologists. When this happens the only section of the uppermost Weybourne Chalk will be that provided by the intermittently exposed beach-platform immediately to the west of the Sheringham Lifeboat House.

A revised section is given in Fig. 7, with the flints given a numerical notation to avoid confusion with the published section. The main difference between the two sections is that the flint 5 [C in Peake and Hancock 1961, fig. 6] is a 30 cm zone of small thalassinoid flints overlain by patchily indurated chalk terminating in a well-defined erosion surface. The Catton Sponge Bed [Peake and Hancock ibid, fig. 6] is thus composite, with a lower hardground - here designated I - succeeded by the main hardground (II) which is locally intensely indurated and has a terminal erosion surface. This erosion surface, which marks the top of the Weybourne Chalk, is overlain by a 'belemnite graveyard' comprising rolled specimens of Belemnitella minor mixed with small flattened soft green (glauconitised?) chalk pebbles. A third incipient hardground (III) occurs near the top of the section, but this does not have a well-defined terminal surface.

Although Catton Grove must have provided a certain amount of museum material labelled 'Catton', it is rather disappointing as a fossil collecting locality, particularly in the Weybourne Chalk section. The lowest chalk visible yielded a poorly preserved baculitid (not collected) and two undiagnostic Belemnitella. Hexactinellid sponge meshworks in limonitic preservation are seen in the chalk immediately underlying the scattered flint 3, but there are no traces of a pink oyster fauna. The interval between flints 3 and 4 is the lowest level at which Carneithyris carnea has been seen in situ in the Norwich Chalk, although records in Rowe MS suggest that it may be represented at lower horizons in the Harford Bridges complex. In the interval between flints 4 and 5 Carneithyris becomes well established (4 specimens in the Leeder Coll.), together with Cretirhynchia woodwardi and Chlamys undulatus (Nilsson); just below flint 5 Carneithyris and a glauconitised mould of Inoceramus ex gr. regularis/balticus were collected, associated with the first definite Belemnitella minor Jeletzky. At approximately the level of flint zone 5 two Cretirhynchia arcuata [Zm 9998-9999] were collected before the section was measured in detail; further examples of this characteristically post-Catton Sponge Bed rhynchonellid are in the Leeder coll. from the interval in the published section between flint C and the Catton Sponge Bed itself. These records demonstrate that C. arcuata enters below the Catton Sponge Bed, and probably below hardground I of this complex, perhaps even coinciding with the first entry in strength of Belemnitella minor; it is also clear that C. woodward ranges up to just below the top of the main sponge bed (II).

The main sponge bed yields a rich assemblage of hexactinellid sponges including Aphrocallistes cylindrodactylus Schrammen, Coeloptychium argaricoides Goldfuss, Lepidospongia rugosa Schlüter and abundant Leptophragma striatopunctata (Schrammen) [for additional species see Reid 1968, p.19]. There is also an aragonite-preservation fauna of small and predominantly undescribed molluscs, conspicuous among which are a Periaulax, Planolateralus aff. berocscirensis (Woods) and one or more species of Nucula.

It is unclear how many of the ammonites in museum collections labelled 'Norwich' come from the Catton Sponge Bed itself rather than from the famous 'Cast Bed' at Thorpe which is very much higher in the mucronata Zone succession. C. W. and E. V. Wright MS gives 'Bostrychoceras polyplocum' [Nostoceras] from Catton Grove, and both that species and Baculites from the stratigraphically equivalent Attoe's pit (see p.88), although the exact horizon was not recorded. The BMNH has a small Menuites portlocki ex Bayfield Coll. [C3112] with 'Catton' written in ink on the specimen.

In addition to the fossils noted above, the matrix of the main Catton Sponge Bed has yielded a Coelosmilia cf. wiltshirei, small brachiopods (Carneithyris, Cretirhynchia arcuata and C. norvicensis [juv] and C. woodwardi) and an Echinocorys near gibba. The Sponge Bed is penetrated by an indistinct Thalassinoides burrow system, the soft fill of which locally incorporates belemnites presumably derived from above. Immediately below the terminal erosion surface are found scattered iron sulphide nodules which have been oxidised to limonite.

Above the main Catton Sponge Bed, fragments of Inoceramus sheets are conspicuous in the chalk, this being particularly characteristic of the Beeston Chalk and not seen in the beds below; an exactly comparable lithological change is seen above the correlative North Antrim Hardground in the Northern Ireland succession (Fletcher and Wood 1978, p.98). Coincident with this occurrence of Inoceramus-rich chalk the character of the flints changes, and many of the apparently widely scattered larger flints (e.g. flint 7 between hardgrounds II and III) are in fact part of flint circles, although this fact cannot always be readily detected in quarry faces. Flint 7 may well equate with the flint circles found at this level on the coast 137m east of Sheringham Lifeboat House.

A significant faunal change occurs above the main Sponge Bed with the extinction of *Cretirhynchia woodwardi* and the incoming of *Cardiaster cordiformis* associated with abundant *Carneithyris carnea* and *Cretirhynchia arcuata*. There are no examples of *Cardiaster cordiformis* from this locality in museum collections, but many specimens were found during a visit by a party from Nottingham University [N.B. Peake: pers. comm.], and the species is recorded from the correlative succession at Attoe's pit. Compared with those from the top Weybourne Chalk, many of the *Echinocorys* from the basal Beeston Chalk at Catton Grove are significantly smaller, being somewhat reminiscent both in size and morphology of the more depressed variants of the *Echinocorys conica* assemblages from Cringleford (Cantley) and Tharston. These echinoids occur just below the giant ring flint 7 and particularly characterise hardground III and its coastal equivalent, the middle sponge bed at Sheringham (see Peake and Hancock 1970, p.339E. The uppermost beds in the pit yielded two small *Belemnitella* cf. '*langei*'.

Peake and Hancock (1961, p.320) noted that large *Ostrea* [i.e. *Hyotissa*] *semiplana* was abundant at Catton, although none was collected in the re-survey, and it is possible that the recorded material came from a lower horizon which is now obscured by talus. Such an oyster-rich horizon would suggest a correlation with the Chalk of the Eaton Golf Course pit. The Brydone coll. [NCM] contains two superbly preserved unregistered bivalved specimens of *Chlamys* undulatus and Plagiostoma marrotianum; and the Goff coll. [NCM] includes an Ostrea triangularis.

STOKE HOLY CROSS. [2536 0140]. Rowe loc. 167; BGS: HBW 332-334; 407-408; CJW 3460-3511; also Goff coll. [NCM]

This now completely obliterated pit (in which a section was excavated by Dr. J. Goff) is of importance in that it demonstrates the lateral continuity of the basal Beeston Chalk succession over a distance of 9.5 km along the strike from Catton Grove, and extends the latter section upwards another 2.7m (see Fig. 7). A similar lateral continuity in the top Weybourne Chalk succession is demonstrated by a somewhat disturbed section in a small pit at Halfway House [2327 0270] (p.79) from which some fossils were collected by Dr. Goff [NCM].

The base of the trench exposed the top of the main Catton Sponge Bed (II), and it is possible that this indurated bed formed the original working floor of the pit, but this could not be determined without extensive excavation. The Woodward collection [BGS] includes a Coeloptychium argaricoides which probably came from this level.

Following the notation adopted for Catton Grove, the ring flint 7 is somewhat smaller, but hardground III is better developed, with a well-defined terminal surface overlain by flattened green chalk pebbles and oxidised iron sulphide nodules. The chalk overlying hardground III yielded small oyster spat-encrusted phosphatised chalk pebbles, Inoceramus sheet fragments and broken rolled isolated valves of Carneithyris and a small pycnodonteine oyster; associated with these essentially pebble-preservation fossils were well preserved Cretirhynchia arcuata, free valves of Atreta nilssoni, Margostrea alaeformis and Pseudoptera coerulescens. A notable record from this horizon is the rare bryozoan Theona disticha (Hagenow).

The top of this bed is slightly indurated, and yielded a rolled weakly phosphatised baculitid steinkern and a single specimen of Kingenella sp. nov., which represents the lowest record of this taxon in the Beeston Chalk (see p.69). The overlying soft chalk is rich in Carneithyris and large Cretirhynchia arcuata, as is the interval between the yellow band and the massive flint zone 10, which yielded large belemnites: Belemnitella minor and a corpulent pseudogranulate variant of the giant B. mucronata sensu Jeletzky [CJW 3471]. The uppermost chalk exposed is yet another (soft) hardground with Carneithyris in pebble-preservation and indeterminate gastropod steinkerns.

Although it has been suggested (Peake and Hancock 1970, pp.339E-F) that the 'upper' sponge bed (i.e. hardground III) of Catton Grove may lie a short distance below the base of Caistor St. Edmunds there is no sign of flint zone 10 at the latter locality, which seems to demonstrate that there can be no overlap between these two sections. A further difficulty lies in the fact that it has not proved possible to correlate the basal Caistor succession with the temporary section exposed at Westlegate (see p.91), although palaeontologically they are strikingly similar. This problem remains to be resolved, but the balance of the evidence suggests that there is a complex of successive major and minor hardgrounds up to at least 6m thick between the top of the Weybourne Chalk and the base of the Caistor section.

**CAISTOR ST. EDMUNDS.** [2390 0466]. Rowe loc. 166. Goff Coll., Leeder Coll. [NCM]; BGS: Hr 454; CJW 3163-3459, 5085-5138; 5277-5296; 5404-5495

This is currently one of the best exposures of mucronata Zone Chalk in the Norwich area, and provides a representative example of the biostratigraphy of the Beeston Chalk subdivision. Peake and Hancock (1961, fig. 6) gave a graphic section of the 30 ft (9.14m) then exposed, designating the various flint courses by letters T to Z reading down from the top. Since then, however, the pit has been considerably deepened, and in summer 1969 it was possible to measure a further 7.16m below the base of the published section. The complete section is given in Fig. 8, with the flints designated numerically to avoid confusion with the earlier alphabetical notation. The deepest part of the section is now flooded, but it is still possible to examine the higher levels down to approximately the level of flint 5 by climbing down the talus slopes above the water level.

The chalk is fossiliferous throughout the succession, but a number of particularly fossiliferous horizons have been recognised of which the most important are: the *Baculites* Bed at the base of the section; the *Neoliothyrina* Bed in the interval between flints 2 and 3; the *Echinocorys* Band of the Peake and Hancock section between flints 8 and 9; and a bed rich in small brachiopods, which can be designated the *Austinocrinus* Bed from the occurrence of scattered columnals of early forms of *Austinocrinus bicoronatus*.

It is of interest that where small brachiopods are particularly common the belemnite assemblage is dominated, at some horizons almost exclusively, by small, slightly lanceolate and weakly vascularised *Belemnitella* resembling but not conspecific with *B. langei* Jeletzky[1]. These *langei*-like forms may have affinities with *B. mobergi* (see Nikitin 1958, pl.14, fig. 4; pl.20, fig. 3) as has been suggested by Peake and Hancock (1970, p.339E). Schulz (1978) referred comparable forms from the German equivalent of the Paramoudra Chalk to *B.* cf. *najdini* Kongiel. It seems preferable, however, to use the indefinite designation *B.* '*langei*' until the inter-relationships of the higher Campanian smaller belemnites have been further investigated.

[*B. langei* s.s. appears to characterise a narrow belt within the equivalent of the Paramoudra Chalk in Germany (Schulz 1978) and has not yet been proved to occur in the Norfolk succession.]

At horizons with a quantitatively restricted small brachiopod fauna the composition of the belemnite assemblage changes significantly, so that approximately 20% comprises larger, essentially cylindrical and well-vascularised forms including _B_. _minor_ and giant (i.e. with a preserved guard length of over 110 mm) belemnites comparable with the proposed _Belemnitella_ _mucronata_ neotype series from Mousehold (Rowe loc. 160) figured by Jeletzky (1964, pl.1, figs. 1, 3, 4).

Some 460 accurately horizoned macrofossils have been collected, of which 116 are belemnites. In addition, there is extensive material in the Goff and Leeder collections although the exact horizons are not known in all cases. With this amount of material it is possible to give a semi-quantitative statement on the distribution and relative abundances of various fossil groups throughout the succession particularly with reference to the main fossil horizons.

The _Baculites_ Bed: this bed yields poorly preserved green-coated steinkerns of indeterminate _Baculites_ sp. and trochid gastropods; from this bed, or possibly from an even deeper level in a trial-hole the Goff collection includes _Baculites_ with a straight-sided ellipsoidal whorl section (?_B_. _vertebralis_ Lamarck), and fragments of _Neancyloceras_ _bipunctatum_ (Schlüter) and a _Neocrioceras_ (_Schlueterella_) sp. The remaining fauna comprises _Carneithyris_ _carnea_ and a single specimen of _Kingenella_ sp. nov. [CJW 5091]. The latter species, which appears to be unrepresented in the pre-Catton Sponge Bed succession, has also been collected by the author from the extreme base of the Beeston Chalk at Stoke Holy Cross, from the _Austinocrinus_ Bed near the top of the present pit [CJW 3194] and it has recently been recorded from the St. James' pit (Whittlesea 1985b). It is probably relatively common at Caistor as there are a further three specimens in each of the Goff and Leeder collections. *Kingenella* reappears in the Lower Maastrichtian *Porosphaera* Beds on the coast at Sidestrand, seven specimens having been recorded by Whittlesea (1985b). This discontinuous distribution parallels that in the Northern Ireland White Limestone (see Fletcher and Wood 1978).

The *Neoliothyrina Bed*: this is named after the occurrence of large (gerontic) *Neoliothyrina obesa*; the remaining fauna includes *Carneithyris carnea*, *Cretirhynchia arcuata*, *Neithea sexcostata* and a small smooth aptychus. The few belemnites collected comprised four *B*. '*langei*' and an apex of the giant form.

The *Orbirhynchia Bed* overlies a slightly hardened omission surface circa 0.5m above flint 2 and has yielded perhaps the most diverse macrofauna encountered in the Norwich *mucronata* Zone. This fauna probably represents a secondary concentration rather than a life assemblage since a high proportion of the brachiopods are disarticulated and broken in the matrix as in the case of the basal Beeston Chalk at Stoke Holy Cross. It is noteworthy that the only *Echinocorys* from this horizon and from the level of flint 2 are very thin-tested forms. The bed is named after the occurrence of a probably undescribed species of *Orbirhynchia* which comprises circa 10% of the brachiopod assemblage; isolated specimens have been collected at other horizons such as the *Austinocrinus* Bed, and it is well represented in collections made by Brydone from the type Beeston Chalk. It should be noted that Pettitt (1950-65) did not record *Orbirhynchia* above the *quadrata* Zone, whereas it is now known that the genus ranges at least to the Lower Maastrichtian *Porosphaera* Beds. The fauna collected from the *Orbirhynchia* Bed is as follows: *Coelosmilia* cf. *wiltshirei* Duncan; *Aeschmella inflata* Hennig;

*Ancistrocrania parisiensis*, small-sized *Carneithyris carnea* [abundant, circa 47% of the brachiopod assemblage], *Cretirhynchia arcuata* [circa 24%], *C. norvicensis* [circa 7%], *Kingena* sp., *Kingenella* sp. nov. [3], *Magas* sp. nov. [wide variant characterising Beeston Chalk], *Neoliothyrina obesa* [4.3%], *Terebratulina* cf. *chrysalis* (Schlotheim), '*Aequipecten*' *campaniensis* (d'Orbigny), *Camptonectes* (*Camptochlamys*?) cf. *striatissima* (Hagenow), *Chlamys cretosa*, *C.* aff. *cretosa* [form with smooth widely separated radial ribs: i.e. *Chlamys cretosa nitida* J. de. C. Sowerby *sensu* Schröder 1882], *Gyropleura inaequirostrata*, *Limatula decussata* (Goldfuss), *Limea granulata* (Nilsson), *Margostrea alaeformis*, *Neithea sexcostata*, poorly preserved baculitid fragments; belemnite assemblage comprising circa 90% small forms including *B.* '*langei*', *Arcoscalpellum maximum sulcatum* (J. de C. Sowerby), *Brachylepas fallax* (Darwin), cidarid radioles and plates indet., *Galerites vulgaris* (Leske), *Metopaster tumidus* Spencer, *Ophiomusium subcylindricum* (Hagenow).

*Orbirhynchia* was also found immediately below flint 3, and in the interval between flints 3 and 4 together with *Carneithyris carnea* and a thin-shelled inoceramid (*Mytiloides*?) with hinge preserved [CJW 3239]. Belemnites occur scattered throughout this and the next interval, but are concentrated immediately overlying the surface at the top of flint zone 5, together with fragmentary echinoderm debris including cidarid and *Phymosoma* radioles.

The succeeding beds up to the top of the lower section were poorly accessible for collecting. In the 0.5m below flint 7 the fragmental *Inoceramus* shell content of the chalk increases markedly and broken sheets are conspicuous in weathered faces as far as flint 9. A few brachiopods - *Ancistrocrania parisiensis*, *Kingena* sp. nov. and the wide variant of *Magas* sp. nov. - were collected immediately below flint 7, but in general brachiopods are not a significant faunal component of the *Inoceramus*-rich beds at the base of the main section. It is at this level that the larger belemnites are well represented (circa 20% of the belemnite assemblage in the *Echinocorys* Band), including *B*. *minor*, the giant *B*. *mucronata* sensu Jeletzky and a single example [CJW 3283] of an extremely elongate fusiform belemnite with a distinctly triangular cross-section, which may belong in the North American group of *Belemnitella americana* (Morton).

The majority of the *Echinocorys* of the *Echinocorys* Band are crushed, but appear to be referable to the undescribed flat-based conoidal forms [*E*. aff. *conoidea* Goldfuss: Peake and Hancock 1961] that characterise the type Beeston Chalk. A second *Echinocorys* horizon is found above a minor hardground immediately overlying flint 11, but here the assemblage comprises smaller globose forms with a more rounded base than those below. The echinoids can occur concentrated in 'nests' and locally become incorporated in flint 11, as in the case of a flint containing some 20 individuals [NCM] which was found during quarrying operations.

The *Austinocrinus* Bed between flints 12 and 13 is again rich in *Inoceramus* sheet pieces but, in contrast to the lower *Inoceramus*-rich horizon, the fauna is dominated by abundant small brachiopods. The *Austinocrinus* are probably transitional between *A*. *rothpletzi* Stolley and the later *A*. *bicoronatus*. The belemnites are exclusively small forms including *B*. '*langei*'. The brachiopod fauna comprises dominant small-sized *Carneithyris carnea* [circa 50%] and *Cretirhynchia arcuata* [30%] with subordinate *Kingena* and *Kingenella*; to date no examples of *Cretirhynchia norvicensis* and *Neoliothyrina obesa* have been found at this horizon. There is also a limited bivalve fauna which includes '*Aequipecten*' aff. *sarumense* Woods, *Margostrea alaeformis* and a juvenile oyster questionably referred to Hyotissa sp.

The overlying beds are characterised by small cuboidal Cretirhynchia ex gr. norvicensis and Kingena sp. accompanied by a Belemnitella 'langei' assemblage; a level of abundant belemnites occurs approximately 1m below the potstone flint 14. This part of the succession appears to match the section exposed by digging at Trowse (see p.92). A small crushed micrasterid [CJW 3302] was collected near the base of the flint 13-14 interval which constitutes an important record, since micrasterids are usually considered to have been replaced by Cardiaster in the Beeston Chalk and there are no definite examples known from this level.

Supplementary information is provided by the Goff collection as follows:

1. The deep section yielded fragments of Chlamys undulatus and pale-coloured Pycnodonte (Phygraea) sp.

2. Ostrea triangularis occurs commonly at the base of the main section, i.e. in the lower Inoceramus-rich belt; this is to be expected since this species appears to have preferentially attached itself to Inoceramus sheets.

3. Coelosmilia wiltshirei and C. granulata are clearly distinct species at Caistor (presumably occurring in the deep section), and no intermediate forms are represented.

**WHITLINGHAM** (Colman's pit). [2678 0766]. Rowe loc. 154. Rowe Coll. [BMNH with the symbol W]; Goff Coll. [NCM]; BGS: CP 283-298; CJW 2998-3104; 5082-5083

[Note: this is neither of the pits referred to by Woodward (1882, pp.80-81) which were presumably the source of the collection [BGS] numbered HBW 241; 249-255; 365-366; 396. These pits, to judge from the Old Series Geological 1" map, lay farther to the east, in the area now known as Old Chalkpit Plantation (see p.94). The larger and more easterly pit exposed the famous tight anticlinal structure figured by Woodward (1876, fig. 21). The presence of such a tight structure suggests the possibility that this, and possibly other pits in the immediate vicinity, were cut into rafts of Chalk enclosed in Drift.]

Whitlingham was one of Rowe's main collecting localities, his MS noting that "fossils are really abundant here, but only through the workmen"; also that "the foreman says that there is no hard chalk here and I have also failed to find any". At that time the section was 60 ft [18.3m] high, but it is not clear whether this figure included the overlying Norwich Crag. When Mr. Chatwin visited the pit in 1925 for the Geological Survey the somewhat ambiguous collecting notes imply that there was at least 12 ft [3.6m] of chalk visible, and possibly as much as 30 ft [9m]. In 1969 a 3.9m section including one or more paramoudras was visible above the talus on the east side of the pit underneath the roots of a tree (Fig. 9), but the lowest 1m is now (1974) obscured by talus, and it is no longer possible to see a paramoudra *in situ*.

Whitlingham provides biostratigraphical information on that part of the Paramoudra Chalk preceding the Thorpe hardground(s) [Paramoudra$_1$], but its position within the subdivision is uncertain. Compared with exposures of white chalk with paramoudras on the coast east of East Runton, the Paramoudra Chalk of Whitlingham is highly fossiliferous with a diverse brachiopod and echinoid fauna. From the Rowe collection it is clear that the micrasterid *Micraster ciplyensis* is well represented, although it is not as abundant here as at the horizon of the Thorpe Asylum pit [Paramoudra$_2$]; Rowe Coll. [BMNH] also has 2 *M*. cf. *glyphus* [E19751, 19753] which constitute an anomalous occurrence in the post-Catton Sponge Bed succession. It is possible that the symbol W marked on these specimens may refer to Weybourne rather than Whitlingham, since Rowe used this symbol additionally for a small quantity of unequivocal Weybourne material.

The succession divides into a lower part with massive semi-continuous tabulate flints joining vertical paramoudras located some 3m apart and an upper part with close-set courses of small flints. An *Echinocorys* horizon with depressed dome-shaped *E*. ex gr. *belgica* is found immediately above a slightly hardened omission surface 38 cm above the top of flint A; this or a comparable horizon could well have been the source of many of the Whitlingham specimens of this form. In addition to corroded and bored *Belemnitella* cf. '*langei*', this bed has yielded '*Aequipecten*' cf. *campaniensis* juv., *Chlamys* cf. *denticulata* (Hagenow), *Neithea* *sexcostata*, a brachiopod assemblage comprising dominant *Carneithyris* and *Cretirhynchia* ex gr. *limbata* [including forms apparently transitional between *C*. *arcuata* and *C*. *limbata* (Schlotheim)] with subordinate *Neoliothyrina* *obesa* and *Orbirhynchia* sp; and *Austinocrinus* *bicoronatus*. Approximately 1m higher a second fossiliferous bed overlying a slightly hardened omission surface yields *Limatula* sp., *Limea* *granulata*, *Pseudoptera* *coerulescens*, *Spondylus* *dutempleanus* and a *Belemnitella* '*langei*' assemblage; the brachiopod assemblage differs from that below in that there are equal numbers of *Cretirhynchia* ex gr. *limbata* and small cuboidal *C*. ex gr. *norvicensis* associated with *Carneithyris*, *Neoliothryina* *obesa* and *Terebratulina* *chrysalis*. In both beds the *Carneithyris* are mainly broken and rolled pebble-fossils, while the other brachiopods, although crushed in many cases, are comparatively well preserved. The upper part of the section has so far yielded only the small cuboidal *Cretirhynchia* ex gr. *norvicensis*, *Cardiaster* *cordiformis* and a *Belemnitella* of the strongly vascularised type with high conical lateral profile which characterises the higher Upper Campanian and basal Lower Maastrichtian in many parts of N.W. Europe. These belemnites have been tentatively referred to *B*. *posterior* Kongiel (Kongiel 1962) from the Vistula Valley, Poland, but there is increasing doubt whether this is correct, and the qualified name *B*. '*posterior*' is adopted here.

In addition to the above records, Rowe found that *Proliserpula* ampullacea and Ostrea triangularis were particularly common; other records of interest are Pinna cf. decussata Goldfuss [BMNH L81097-8] and a rolled flint steinkern of the Lower Maastrichtian Galerites abbreviatus Lamarck [BMNH E38510] from the Crag Stone Bed.

**POSTWICK GROVE** [2866 0801]. Goff Coll. [NCM]; BGS: CJW 2883-2912; 5362-5380

This 2m section in the former river cliff is at or about the stratigraphical level of the Thorpe Tollgate pit, and probably represents the highest in situ Upper Campanian in Norfolk. The lowest chalk seen is white; immediately above this there is a massive anastomosing thalassinoid flint with obliquely sloping cylindrical extensions, this being enclosed in an orange-yellow, weakly indurated chalk containing hexactinellid sponge meshworks and poorly preserved moulds of aragonitic molluscs including gastropods and baculitids. Overlying this is a unit of patchily indurated orange/white mottled chalk with many small Carneithyris, a small pisiform Cretirhynchia aff. arcuata, Micraster fragments and juvenile Belemnitella 'posterior'. This is succeeded by semi-laminated 'buttery' chalk which has not yielded any fossils. The top of the section is formed by a single or complex intensely hard and locally porcellanous chalkstone with a line of flints. The fauna from this hard bed includes gryphaeate Pycnodonte (Phygraea) sp., small brachiopods as below, and occasional small Belemnitella cf. 'posterior'. Goff Coll. material from this locality includes a large Echinocorys ex gr. belgica and Austinocrinus bicoronatus.

### Supplementary mucronata Zone sections

#### (i) Tas valley

**THARSTON FURSE HILL.** [TM 1940 9560 not 188 948 as in Peake's list]. Rowe loc. 49. Extensive material in the Rowe Coll [BMNH] with the symbol 49 [NB this must not be confused with material from the Lincolnshire loc. 49 (Wyham House)]; BGS: CJW 5206-5243

Although this was one of Rowe's most fossiliferous localities there are no surviving MS notes beyond a very long faunal list and a stratigraphical assignment to a basal position in the zone; the common occurrence of *Echinocorys* ex gr. *conica* provided his 'Tharston Line'. The Rowe Coll. includes 2 '*Aequipecten*' sp. nov. aff. *sarumensis* [LL8169], 2 adnate *Crania* sp. [B93509-10], *Neoliothyrina obesa* [B51311]; 5 *Belemnitella* ex gr. *senior* [C45052-6], *Micraster glyphus* [E19776] and 2 *M*. (*Isomicraster*) aff. *stolleyi* with retracted labrum [E34721-2]. In addition there is a large suite of *Echinocorys* [E35048-78] comprising 26 *E*. ex gr. *conica* and 5 *E*. *subglobosa*; the majority of these are flint-infilled, 10 of the *conica* group and 4 *E*. *subglobosa* being perfect and undistorted. The *conica* group includes several relatively large forms with rounded apex and ambitus comparable with forms from the Cantley pit, Cringleford (p.83) and the Cringleford sewerage scheme sections (p.81) - and quite distinct from the smaller angulate forms of the Drayton/Bowthorpe assemblage. Of particular note is an intermediate growth stage of *E*. *subglobosa* [E35066]: this species is usually represented by large individuals, and the specimen in question emphasises the morphological differences between this group and specimens of the *conica* group of comparable size.

The pit is almost completely overgrown and hidden in woodland, with only a well-preserved lime-kiln giving some indication of its former position. Trenching into the sides of one of the deepest hollows revealed 1.3m of soft yellow chalk overlying a basal 15-cm thalassinoid flint with the 'horns' directed upwards. Fossils occurred relatively commonly between this flint and scattered 8-cm flints at the top of the section.

The author's material includes *Cretirhynchia* aff. *lentiformis* [more markedly costate than in Weybourne Chalk? and possibly equivalent to 'C. lentiformis a' of Leeder (1969)], Margostrea alaeformis, Pseudoptera coerulescens, Spondylus dutempleanus, 10 Belemnitella ex gr. senior; chalk-filled Echinocorys ex gr. conica with adnates, radioles of Phymosoma sp. and Stereocidaris sp.

The exact position of this locality within the pre-Weybourne succession is uncertain, but the apparent absence of the giant conical variant of Echinocorys ex gr. conica, Galeola papillosa basiplana and Galerites? minor Rowe MS combined with the relative abundance of Belemnitella ex gr. senior is suggestive of Pre-Weybourne$_3$. The characteristic flint-infilling of the echinoids and a tendency to superficial iron-staining matches material from the Cantley pit, Cringleford, with which this section appears to correlate on faunal grounds.

**FLORDON COMMON.** [TM178 976].

Chalk was exposed below gravels in deep holes in the eastern part of the pit. Porosphaera globularis and small Echinocorys test fragments were observed in weathered spoil, but no biostratigraphically significant fossils were present. The Chalk is presumed to be older than that at Tharston Furze Hill.

**PIT S. OF FLORDON CHURCH.** [TM 189 972]. Peake loc. 190 Site exists, virtually no chalk showing in 1974.

**TASBURGH.** [TM 203 955]. Rowe loc. 50. Not examined.

**NEWTON FLOTMAN** (Limekiln Farm). [TM 2106 9830]. Rowe loc. 50
BGS: CJW 3785-92.

1.5m chalk visible in 1969 above buried adit entrance: 1.10m soft yellow chalk with occasional belemnites; semi-continuous thalassinoid 'spiky' flint (10 cm); top 40 cm tough yellowish chalk. The fauna comprised 6 non-diagnostic Belemnitella fragments and an Echinocorys test fragment with adnate *Pyropora*. From its geographical position this pit is presumed to be in Weybourne Chalk.

**HALFWAY HOUSE.** [2330 0268].

The pit is now degraded, but a trench cut into talus in 1971 exposed Catton Sponge Bed hardgrounds I and II, and the top of the Weybourne succession down to the equivalent of Flint 3 of Catton Grove (see Fig. 7). Some fossils were collected by Dr. Goff [NCM] including a small *Echinocorys* sp. of basal Beeston Chalk type.

(ii) *Yare valley south and west of Norwich*

**COLNEY.** [1700 0927]. Rowe loc. 178. No section visible.

Rowe MS: faunal list includes "*B. mucro* 9 (large), *Echinocorys* fragments, *R. limbata*, *Lunulites cretacea*, *Cidaris subvesiculosa*". None of this material can be found in BMNH.

**BOWTHORPE HALL:** [1760 0908]. BGS: CJW 3756-84

Highly fossiliferous chalk is exposed beneath tree roots on the N. side of a small pit; there are many flints with fossils lying on the floor. The fossils include *Glomerula gordialis*, *Cretirhynchia lentiformis*, *Kingena pentangulata*, *Neoliothyrina*? sp. nov?, *Chlamys mantelliana*, *Limatula* cf. *decussata*, *Margostrea alaeformis*, adnate *Pycnodonte*, *Spondylus dutempleanus*, *Belemnitella* ex gr. *senior*, *Arcoscalpellum maximum*. The Chalk is presumed to be older than the pre-Weybourne$_3$ of the Bowthorpe Hall sewer section, but to still fall within this faunal belt.

**BOWTHORPE HALL.** [1802 0903]. Rowe loc. 177. No chalk visible.

Rowe MS: "Medium sized, a few feet of broken up chalk above talus, can't trace flint lines. The 'Cley Line'! A poor surface but v. valuable. One wavy flint course. *Volvolunulites*, *B. mucro* 3."

**COLNEY HALL.** [1755 0790]. Row loc. 176. Not examined.

Rowe MS: "Small disused pit now a fowl run inside the Lodge gates of Colney Hall. Surface moss-grown. *B. mucro* large 2, *Echinocorys*, *Coelosmilia laxa*."

This locality probably equates with Drayton (Rowe loc. 152) as it is on the same north-south line and at the same altitude.

**COLNEY:** excavations for grid station [181 081]. Leeder Coll. symbol Co [NCM]

Leeder MS: "4 ft [1.2m] chalk seen - becomes very hard in middle of section above and slightly below a band of carious flints which assume spindly irregular shapes or large nodular ones; chalk at surface at 45 ft [13.7] OD .... undoubtedly equivalent to Food Centre hardground."

The Leeder collection includes 2 small silicified bored belemnites, indet. pink oyster fragments, *Plicatula hantoniensis* and an aptychus; associated but un-numbered is a specimen of *Volviflustrellaria taverensis* preserved in flint.

**COLNEY:** excavation for Food Centre. [1835 0780]. Leeder Coll. (F.R.I.) symbol FC [NCM]

Leeder MS: "7 ft [2.1m] chalk with basal 1 ft 6 in - 2 ft [0.45-0.60m] bed of hard yellow chalk. Large, c.1 ft [0.30m] long, nodular flints on tips not seen *in situ*. Very hard chalk in many echinoids - dog-tooth calcite in interiors. Chalk surface 40 ft [12.2m] OD".

The fossils collected by Dr. Leeder include 7 *Echinocorys* ex gr. *conica*, 2 *E. subglobosa*, *Micraster* cf. *glyphus* [juv.], *Phymosoma* sp., cidarid radioles indet. The belemnites are mainly bored and corroded. The *Echinocorys* ex gr. *conica* exhibit a tendency towards long apical discs, but otherwise match those from Bowthorpe Hall sewer sectio material.

**COLNEY:** temporary excavation exposing 1.5m face over about 50m. [Approximately 184 075]. Leeder Coll. symbol Ne [NCM]

The fossils collected by Dr. Leeder include a fragment of the base of *E.* ex gr. *conica* and numerous very well preserved *Belemnitell* sp., some of which have white 'skins'. These belemnites are anomalou elongate forms which do not seem to belong to the *senior* group: tw (Ne 2, 15) exhibit extreme elongation and a degree o 'pseudogranulation' reminiscent of forms from the Lower Maastrichtian

**COLNEY:** old pit on UEA land [1846 0740]. Less than 1m white/orange-yellow banded chalk exposed by digging in 1969. BGS: CJW 3750-55

Fauna non-diagnostic: _Chlamys_ _mantelliana_, small pycnodonteine oyster, _Belemnitella_ fragment indet, test fragment _Echinocorys_ ex gr. _conica_, cidarid radiole.

**COLNEY-CRINGLEFORD SEWERAGE SCHEME** [189 074-190 072]: temporary section in Earlham Park on opposite side of river to Cringleford (Newfound Farm) pit. Leeder Coll. symbol B [NCM]

Leeder MS: "maximum of 8-9 ft [2.4-2.7m[ seen; one flint course of medium tabulars seen in spoil. Chalk surface 25 ft [7.6m] OD; Chalk overlain by 5 ft [1.5m] alluvium".

The fossils collected by Dr. Leeder include: _Cretirhynchia_ _lentiformis_ [rare, 1 specimen only], _C_. cf. _woodwardi_, _Kingena_ _pentangulata_; _Neithea_ _sexcostata_, small pycnodonteine oysters [common] _Spondylus_ _dutempleanus_, _Echinocorys_ ex gr. _conica_, _E_._subglobosa_, _Galeola_ sp., _Micraster_ sp. The _conica_ group _Echinocorys_ differ from the Food Centre/Bowthorpe Hall assemblages in that they are much more rounded at the ambitus, and have rounded and pointed rather than elongate angular apices; some sewerage scheme forms have an almost circular base, and thus trend towards the large form characterising Pre-Weybournes, i.e. Brydone's Eaton Chalk. Most of the echinoids are bleached white, and many exhibit extensive (gastropod?) borings in the apex; others carry an assemblage of adnates including _Porosphaera_ _sessilis_, _Retispinopora_ sp., _Epiphaxum_ _auloporoides_ Lonsdale _Stomatopora_ spp. and membranimorph bryozoa, _Gyropleura_ and _Pycnodonte_. Only one of the echinoids is flint-filled, and the majority exhibit some degree of crushing. The _Belemnitella_ assemblage includes many slim elongate forms, a single example of the extreme elongate pseudogranulate form known from Leeder's Colney locality Ne, and a number of small lanceolate forms reminiscent of the `_langei_' group of the Beeston-Paramoudra succession. 50% of the assemblage is white-

'skinned' as at Colney, and thus very well preserved, but it has not proved possible to split them to investigate the internal morphology. This locality presumably equates with the lower (unexposed) part of the Newfound Farm pit and lies some 6-9m below the pre-Weybourne$_5$ succession at UEA.

**UEA:** temporary excavations near University Library [approximately 193 076]. Leeder Coll. symbol U [NCM]

Leeder MS: A 7 ft (2.1m) section some 15 ft (4.5m) below the original ground surface included a "discontinuous band of hard chalk blocks" with intense iron-staining, pockets of limonite and limonitised pyrite nodules; this hard band was developed above and below a course of large tabulate flints which Leeder equated with Flint C of the Eaton Limeworks section.

The UEA site yielded a typical 'Eaton' - i.e. Pre-Weybourne$_5$ - fauna comprising the giant conical *Echinocorys* with a flat circular base, *E. subglobosa* [with adnate *Praelacazella* sp.] and 4 *Galeola papillosa basiplana*. The brachiopods include *Kingena pentagulata*, *Magas* sp. nov. and common *Cretirhynchia lentiformis*, the relative abundance of the latter species contrasting with its rarity in the sewerage scheme excavations. The *Belemnitella* assemblage [40 specimens] comprises predominantly corroded and bored guards in unsuitable condition for splitting: the majority of the belemnites, especially the larger specimens, came from the 'hard band'. *B.* ex gr. *mucronata* predominate over *B.* ex gr. *senior*. The supplementary fauna comprise serpulids; *Chlamys mantelliana*, *Spondylus dutempleanus* and small pycnodonteine oysters.

**CRINGLEFORD** [1940 0618?]; Rowe loc. 183.

Rowe MS: "Small disused pit in pasty chalk at corner of field opposit the garden gate of Oaklands. Mr. Harmer says that there use to be a distorted flint course showing. *B. mucro*, 1 *R. limbata* 1."

This is presumed to be the pit [1940 0618], which exposed a metr or two of chalk on the back face until 1976 when it became obscured.

**CRINGLEFORD.** Rowe loc. 184. This locality cannot be identified

**CRINGLEFORD (CANTLEY) PIT:** [181 050].

Chalk exposed under gravel in 1935-6 yielded the suite of 19 large Echinocorys ex gr. conica in NCM marked 'Cringleford' and subjected to semi-statistical analysis by Hayward (1940, pp.81-2, pl.2, figs. 2a, b). A further 3 specimens from this locality belong to the large species E. subglobosa. The preservation (undistorted, flint-filled and iron-stained) closely matches material in the Rowe coll. [BMNH] from loc. 49 (Tharston) and a similar range of variants is represented. The locality, which is now reported to be back-filled and levelled, aligns north-south with the Colney Food Centre locality, and is approximately at the same elevation.

**INTWOOD:** [1924 0468]. BGS: CJW 3740-49

Small pit in much reconstituted soft orange-yellow chalk with lines of irregular flints; the relatively high elevation (c.60 ft [18.3m] OD) suggests a raft, although the original bedding is still preserved. The fauna comprises Glomerula gordialis, Lunularia sp., Belemnitella fragments including B. cf. senior and a pseudolanceolata form, Crateraster sp. [marginal], coarsely spinose Stereocidaris radiole. This locality clearly belongs in the Pre-Weybourne succession on the belemnite evidence.

**FIR HILL:** [2018 0465].

Small pit exposing badly weathered chalk with flints in degraded section. Pink oyster and pectinid shell fragments were seen by the author but were not collected. No stratigraphical assignment is possible.

(iii) Wensum valley

**TAVERHAM:** [1418 1328]; Rhodes loc. 29. Blake (1888, p. 8: "Taverham, Ringland Wood"); BGS: R 3020-16.

This section no longer exists. Rhodes collected Callodictyon?, *Porosphaera globularis*, *Dungulia*? ['*Parasmilia*'], *cylindrica*, *Belemnitella* fragments [not *Gonioteuthis* as implied in 1888 Memoir]. The belemnite fragments are bored by clionid sponges and have adnate *Atreta* and *Stomatopora*: they are specifically indeterminate, but are questionably assignable to the forms characterising Pre-Weybourne$_{1-2}$.

**TAVERHAM PARK LODGE PIT:** [1474 1386]. Brydone Coll. [NCM]; BGS: CJW 5297-5308.

The pit still exists but is almost completely degraded except on the south side where there is a small section exposed beneath tree roots.

The Brydone Coll. contains poor *Belemnitella* fragments with moderately strong vascular traces and very acute fissure angles: as in lowest *mucronata* Zone forms from Northern Ireland and Hants.

Fossils collected by the author comprise *Inoceramus* hinge fragments and shell chips, *Limea granulata*, an indet. *Belemnitella* alveolar fragment, and *Stereocidaris* radioles.

This locality may be Rowe loc. 170 ["old and very small pit opposite wall of Taverham Park (2 gates close by in Park wall)"], although Rowe marks his locality in a totally different position on the map.

Rowe MS: "*B. mucronata* 2, *Gyropleura* 1, *Coelosmilia laxa*, *Kingena lima*, *R. limbata*, *Echinoc*. frags., *Ino*. frags., *Bourguetic*. 2; section too small to see if flints are in position. Only a few of dirty chalk, moss grown showing under soil. Chalk broken up. Cortices rather thicker than in Norwich Chalk".

**TAVERHAM** 275m N. of church. [1616 1408]. Rowe loc. 186; Rowe Coll. [BMNH]; Brydone Coll. [NCM]; BGS: CJW 3819.

The section is degraded and virtually completely back-filled.

Rowe MS: "old pit of medium size .... chalk firm with several yellow bands in it. They are not hard as at Cley, but the same yellow laminated chalk is seen. A small recent surface has been made otherwise it is entirely obscured. Section originally circa 18 ft [5.5m] deep".

[N.B. Peake (pers. comm.) reported seeing till *beneath* Chalk at one end of the section, and considers that this pit is probably cut in a raft.]

The fauna cited by Rowe MS includes: "*B*. *mucro* 12, *Volvolunulites* 11 [D43228-37]. *Gyropleura* 3, *R*. *plicatilis* (small, like 49) 2, *limbata*, 1-, 6-, and 7-angled serpulids, *Echinocorys* [E41269: "only one found and that chiefly a chalk cast but the shape and size suggestive of Tharston shape variation"]; *Coelosmilia* *laxa*". The *Echinocorys* is very poorly preserved but can be attributed to the *conica* group: Rowe subsequently made the MS comment "the only *Echinocorys* found in the *Volvolunulites* horizon up to 1914".

This is a Brydone locality for *Volviflustrellaria* *taverensis*; Brydone (1932, p.118) recorded *E*. *scutatus* var. *subconicus*: this *conica* group variant is in NCM and clearly differs from the forms of the Drayton/Bowthorpe/Food Centre assemblage in its flat base and symmetrical profile. The Brydone Coll. also includes a curious and possibly pathological *Belemnitella* from 'Taverham Limeworks' which is presumably the same locality: this is a smooth, weakly vascularised guard, markedly pseudolanceolate in ventral view, which may be a derivative of the *praecursor* group.

The only fossil collected by the author was a *Sclerostyla* *macropus* adnate on the alveolar half of a *Belemnitella* suggestive of lowest *mucronata* Zone *praecursor* group forms.

**COSTESSEY:** [169 114]. Rowe loc. 150. Not examined, but site probably overgrown.

Rowe MS: "Chalk v broken up with few smallish flints and these not in v regular lines. *B*. *mucro* common, *T*. *carnea*, *P*. *glob*., *Echinocorys*, *Inoc*. frags, *Ep*. *auloporoides*, *Coscinopora*".

A highly vascularised, corpulent *Belemnitella* ex gr. *senior* [BGS: HBW 397] may have come from here, or from one of the Costessey chalk-pits marked on the Old Series 1" Geological map at about [176 121] and [1820 1216]. The former is in the middle of a residential area, and is probably built over; the latter is a private garden with no Chalk visible at present.

**COSTESSEY:** old pit with cemetery to the N of St. Walstan's Roman Catholic Church [1732 1162]. BGS: CJW 3793-94

The section is completely degraded, and no chalk is visible, but flints on the floor of pit incorporated fossils including an indet. Belemnitella and a fragmentary Echinocorys, questionably attributable to the conica group, suggesting a position in the Pre-Weybourne succession.

**DRAYTON**, pit close to church [1801 1383]. Not examined

Rowe MS: "Chalk much broken up and iron-stained. Several pipes one very large. Flints of good size. Chalk probably glaciated but harder than usual. Flints scattered promiscuously. B. mucro c., Echinocorys large 1, Crania costata 2, Volvolunulites 1, T. carnea".

The occurrence of Volviflustrellaria together with the position of this pit relative to the main Drayton locality (Rowe loc. 152) suggests a Pre-Weybourne$_3$ position. The record of "T. carnea" may relate to Neoliothyrina? sp. nov.?

N.B. this locality may be the same as Brydone's 'Drayton Glebe' which yielded small rhynchonellids and Belemnitella ex gr. senior [NCM].

**HELLESDON**, pit in Marlpit Lane. [1953 0985]. Rowe loc. 185. Not examined.

Rowe MS: "Only small and a poor surface left. Long abandoned. B. mucro 10, R. limbata 3, lentiformis 2, Coelosmilia laxa, common Ech. frags., Magas 2".

**LOWER HELLESDON**, Pearce's Whiting pit. Grid reference uncertain, see below. Rowe loc. 164.

Peake gives [212 106?] for this locality where rough ground but no actual pit is marked on the 6" map. On Rowe's copy of the Old Series Geological 1" Sheet the number 165 is pencilled against a pit at [2081 0950] and also against the pit at [2178 0935]. The exact locality therefore remains in doubt, although there is clear evidence of a former pit at yet another nearby locality [2115 1105]. Near this last locality temporary excavations for a new factory during June 1975 exposed a 2-3m section with a semi-continuous nodular tabulate flint breaking with a vertical fracture and closely comparable with flint T of the Weybourne stratotype. Several Cretirhynchia lentiformis were noted but not collected.

**EARLHAM LIMEWORKS** = Earlham Grove, Dereham Road; Boatman's pit, Bullock's pit. [201 093], not [205 093] as in Peake's list. Rowe loc. 156; Rowe Coll. [BMNH with symbol D"]; BGS: HBW 256-8; 335-46

Rowe MS: "upper beds heavily Fe stained and broken up just like that of Tharston. Lower down it gets as blocky as it ever does at Norwich. Pit 90 ft [27m] deep. Water begins to come in at 60′ [18m] same as at 155. Conulus/small Echinocorys band comes in at about 55′ [16m] same as in no.155. much mostly black with no cortices. Other courses are quite grey. In 1904 there was a paramoudra 80′ [24m] down from top of Chalk. Numerous adits here have been dug for chalk some as many as 40 years ago". E. bayfieldi [27 specimens] and C. minor are found at base of pit and chiefly occur in a space some 12′ [3.6m] thick above a notably strong flint hand. They are rare for 5′ [1.5m] below that band."

Rowe additionally listed the following: "B. mucro [C45060], T. semiglobosa - new form, Kingena lima 3, R. lentiformis R.C., O. vesic large N. forms, Magas p. 2, Argiope 2, R. limbata, R. plicatilis".

**WEBSTER'S PIT, STONEHILLS, DEREHAM ROAD:** [210 092], not [201 093] as in Peake's list. Row loc. 155] Probably = pit recorded by Woodward ( 1882) east of Norwich Union Workhouse with 20 ft [6m] of sand and pebble gravel overlying Chalk. Rowe Coll. [BMNH with symbol D′]; possibly also BGS, but not readily separable from material from Earlham Grove: CP 27;9-80.

Rowe MS: "Deep section. Numerous courses of rather large nodular flints, black with no cortices. Ch. the usual N. type. The pit is 60′ [18m] deep, they cannot work it any lower because of the water. The small conuli were all found within a few feet of extreme base of section. The small Echinocorys also found at the same level. Unless they sink another hole here these echinoids won't be found again as they have started to fill the old sinking up. B. mucro [C43682, 45060], T. carnea strangely rare here and at 156. Magas pumilis 1, K. lima 2."

N.B. it is clear from the Rowe MS information that his locs. 156, 155 and 158 [Cunnell's pit Newmarket Road = Eaton Limeworks], exposed essentially similar succesions with Eaton Chalk sensu Brydone (Pre-Weybourne$_5$ of this account) being exposed only at or near the base, and the greater part of the faces being cut in Weybourne Chalk.

(iv) Norwich - central area

**ATTOE'S PIT, NEW CATTON.** [231 111]. Rowe loc. 195. Rowe Coll. [BMNH with symbol C]; Brydone Coll. [NCM] and BGS: Ya 3070-84; BGS: HBW 378-84, Hr 459-62, CP 167-84.

A small section was visible in 1948, but the pit has since been back-filled and made up to 20 ft [6m] above original surface.

Rowe MS: "Forty ft [12m] of chalk, they come to water in 6 ft [1.8m] below this. In 1904 I noted that the section on the left as one entered the pit was the richest. It is now talused and smeared with downwash, but it is still the richest. This is the upper 10 ft [3m] under the drifts. Conulus found here by me in 1911. T. carnea very large and common in striking contrast to the rarity in 155, 156 and 158. The wonderful abundance of R. limbata and C. lentiformis in 158 has no counterpart here as I only found 7 of former and none of latter. Find out if these mark a horizon. R. plicat. and v. octa by the dozen and large. Is there more than one Conulus bed? H. Attoe says that the hard beds were not found in his uncle's pit (Old Catton) on the other side of the hill ... Pit of good size with about 40 ft [12m] chalk showing of usual Norwich type. Men do not keep fossils. Flints generally black with no cortices. There is a band of hard yellow chalk 10 ft [3m] thick within 10 ft [3m] of top of the pit. Note the bed in other pits. It is not worth burning as it takes too much coal. Extraordinary abundance of spines of Cyphosoma and Salenia."

Rowe is clearly describing a typical Beeston fauna, and it would appear that the section when he saw it must have been closely comparable with that exposed in the nearby Catton Grove pit, i.e. $\text{Weybourne}_3$ and basal Beeston Chalk.

**EDWARD'S PIT, MOUSEHOLD** = Magdalen Chapel of 19th Century collectors. [236 105]. Rowe loc. 160. Rowe Coll. [BMNH with symbol M]; BGS: HBW 394-5, CP 217-40.

Rowe MS: "3 ft [1m] thick of very hard white chalk (not yellow), so hard that they cannot burn it is found 40 ft [12m] from top of chalk".

N.B. Apart from a detailed faunal list on a separate sheet this is the only information that can currently be found relating to this pit in Rowe MS, although Mr. Peake [pers. comm.] recalls that he has seen a 1912 notebook with three pages of observations including a rough section of a 30 ft [9m] deep hole in the floor of the pit from which most of the fossils came. Mr. Chatwin's collecting records [BGS archives] show that there must have been at least 3.6m of chalk above the pit floor.

This locality, today marked only by a limekiln, is the apparent source of an enormous quantity of Beeston Chalk fossils in the Rowe Coll. [BMNH], particularly pectinids, but also including Jeletzky's proposed neotype [C43542] Belemnitella mucronata (Jeletzky 1964). Although this material is faunally homogeneous it should be noted that at various periods in the history of this pit chalk may well have been brought there from other pits for burning in the kiln, so that the provenance of any fossil not collected in situ may be open to question (see Peake and Hancock 1966 and Christensen et al. 1973).

**ST. JAMES PIT.** [292 094]. Peake loc. 192 BGS: HBW 311-331a; 392-3; 425-6; CJW 3105-25.

This was originally a very large pit, but little more than 2m is exposed at present. Woodward (1882) recorded columns of paramoudras, and it is likely to judge from its position and topographical level that this pit was cut in the top of the Beeston Chalk and (possibly) the lower part of the Paramoudra Chalk.

In the resurvey the chalk was found to be yellow, massive and comparatively indurated, with a high content of fragments of Inoceramus shell as at Caistor St. Edmunds; the topmost metre below the Norwich Crag Stone Bed contained numerous brachiopods and belemnites: Carneithyris carnea, Cretirhynchia norvicensis; Belemnitella 'langei' and B.mucronata sensu Jeletzky. This is a typical Beeston Chalk fauna and tends to confirm the Beeston aspect of the Woodward material which includes, in addition to long ranging species such as Neoliothyrina obesa, Neithea sexcostata, Ostrea triangularis and Spondylus dutempleanus, stratigraphically restricted species such as Belemnitella minor, Cymatoceras bayfieldi, tuberculate

Nostoceras (Bostrychoceras) sp. and Galerites vulgaris.

Peake and Hancock (1961) noted Magas pumilus and abundant 'Isocrinus' ossicles, the latter presumably being columnals of Austinocrinus. This crinoid is also represented in a collection [NCM] made by Mr. P. Whittlesea, which includes Coelosmilia granulata, the Orbirhynchis sp. nov. characterising the Beeston Chalk, Limatula decussata and Margostrea alaeformis. Of particular note in this collection are a 'Lima' dunkeri, and two specimens of the rare pectinoid 'Pecten' trigeminatus Goldfuss, hitherto known in the Norwich Chalk only from unlocalised specimens in old [NCM] collection.

Mr Whittlesea has also recently recorded (1985b) Kingenella kongieli Popiel-Barczyk from this locality, a species originally described from the Upper Maastrichtian of Poland. Other records of this brachiopod by Mr Whittlesea and by the author are discussed on p.69 as Kingenella sp. nov.

**Pit near ST. MATTHEW'S CHURCH, THORPE HAMLET** = Bishop's Bridge pit or Lollard's pit. Woodward 1882, pl.2, fig.3. [241 089 or 241 087]; Peake loc. 187. BGS: HBW 223, 263-6, 270-85, GSM 114237.

Peake quotes [241 098], i.e. behind the gasometer immediately S. of Gas Hill [where 'Lollard's pit' is shown on current street maps], but descriptions in the Memoir suggest that the former pit [241 087] near St. Matthew's Church is equally likely.

The two localities are, however, probably only the northern and southern limits of a whole line of workings into the river cliff at approximately the same stratigraphical level. Apart from the figure in the 1882 Memoir there is no available stratigraphical information relating to this pit. Mr. Peake reports [ pers. comm.] that there is still a section with adits exposing Chalk at about [241 087], but it is behind commercial buildings and access has not been sought.

Woodward's material from the Lollard's pit includes several specimens of Galerites ex gr. vulgaris indicating a Beeston horizon. Also represented is a tooth of Mosasaurus - for which the pit was famous - and shark's teeth including Notidanus microdon Agassiz, Pseudocorax affinis (Agassiz), P.laevis Leriche and Synechodus lerichei Herman. S. Woodward (1833) quoted Bishop's Bridge as a locality for sheets of Inoceramus to which he applied the [invalid] name I. giganteus. Also known from this locality is Pholadomya stewarti Tate [NCM 2186], a species which characterises the South Antrim Hardgrounds in Northern Ireland.

**WEST POTTERGATE STREET** (South side): Peake gives [222 087].

This 19th Century locality is now built over.

**'THE BACULITE PIT'**, South side of St. Giles Street (by City Gaol). Peake gives [118 086]; Peake loc. 189

This pit in presumed Weybourne Chalk was the source of many of the baculitids in early collections (notably Fitch). Baculitids are, however, at least as common at certain horizons in the Beeston Chalk, and there are in fact no specimens unequivocally attributable to this locality. Ostrea and corals were said to be common (Woodward 1881). Rowe MS has the intriguing comment: "pit on opposite side to Cunnell's pit Newmarket Road was where Fitch got his Baculites".

There are also numerous references to a locality at St. Giles Gate(s). Peake lists this as locality 195 and quotes underground workings at [223 086]. This locality provided the type specimen of Pinna sulcata S. Woodward (Woodward 1833, pl.5, fig. 23), and a record of 'Ammonites catinus' for which no substantiation can be found.

**WESTLEGATE**, deep excavations for foundations of Norwich Union building. [2308 0818]. NCM: large collection registered under 417:971; BGS: CJW 5256-76.

This was a richly fossiliferous temporary section in Beeston Chalk, approximately equivalent to the base of Caistor St. Edmunds, with several indurated iron-stained horizons preserving an aragonite-shelled fauna including gastropods and ammonites. Although a section was taken at the time by Mr. B. McWilliams [NCM], this is difficult to interpret, and is not included here.

The NCM material includes a large suite of belemnites (mainly B. minor and B. 'langei') poorly preserved gastropods, ammonites including baculitids and a large inflated scaphitid; and numerous brachiopods with dominant Carneithyris and subordinate Cretirhynchia norvicensis, Neoliothyrina obesa, Orbirhynchia sp. and Terebratulina cf. chrysalis. The very limited BGS collection includes the long-ranging molluscs Limea granulata, Limatula decussata and Neithea sexcostata. A noteworthy record is the rare bryozoan Apsendesia harmeri Pergens. The chalk here is notably rich in asteroid marginals and Chomataster alseni Schulz and Weitschat, C. cf. spenseri Rasmussen and Recurvaster sp. are well represented.

**NEW TELEPHONE EXCHANGE:** excavations for the foundations of this building [226 087] exposed a section of Weybourne Chalk, but no information is available.

Deep excavations [229 081] for foundations between St. Stephen's Street and the Bus Station [229 081] proved Catton Sponge Bed below circa 15m of gravels. Mr. Peake [pers. comm.] was informed that numerous Echinocorys were found by the workman, but unfortunately none of these was seen or preserved.

**BRACONDALE:** degraded pit exposing circa 2m chalk beneath Norwich Crag at north-west end. [239 0476]. BGS: CJW 3674-85.

From its geographical position, this pit was presumably cut in Beeston Chalk, this horizon also being indicated by the presence of Inoceramus sheet fragments. 2 juvenile belemnites, probably Belemnitella 'langei', were also collected.

(v) Yare valley east of Norwich (south side) from west to east

**CROWN POINT PIT, TROWSE NEWTON.** Peake gives a general reference [250 069] to what must once have been a complex of workings, but a circa 5m section was actually trenched at [2496 0683] beneath the

Norwich Crag Stone Bed. BGS: HBW 215-26, 267-9, 308-10, 347-62; CJW 3126-62A.

Although apparently in situ, the Chalk formerly exposed in this pit is considerably disturbed and contorted (see Woodward 1882, pp.135-6, pl.8, figs. 24-5) and much if not all of it is probably part of a gigantic 'raft' comparable to that earlier postulated (p.14) for the Deighton Hills. The uppermost part of the section trenched during the resurvey, however, contains two flint courses which can tentatively be matched with flints 14 and 15 of Caistor St. Edmunds, the underlying 3m of flintless chalk corresponding to the virtually flintless interval between flints 12 and 14.

Much museum material labelled 'Trowse', is presumed to have come from here, including the lectotype and paralectotype of Terebratula carnea J. Sowerby and of T. elongata J.de C. Sowerby, both taxa now falling into Carneithyris carnea.

The Woodward material includes numerous Carneithyris carnea, Cretirhynchia norvicensis and (cream-coloured) Pycnodonte (Phygraea) with low umbo and poorly defined posterior wing; other records are the cirripede Arcoscalpellum maximum sulcatum (J. de C. Sowerby) and the coral Coelosmilia laxa, the latter being somewhat unexpected at this horizon and therefore possibly open to question. Fossils collected by the author comprise a low-grade Beeston fauna, the only noteworthy records being the bryozoan Onychocella rotundata Voigt, and several specimens of Echinocorys aff. conoidea incorporated in a flint which was found lying on the floor, but which had probably fallen from the level of the potstone flint course thought to equate with Caistor 14. The belemnites from this section [Belemnitella 'langei'] tend to confirm the stratigraphical correlation with Caistor.

**TROWSE:** Rowe locality (but not separately numbered by him) comprising small pit years since grassed over in what was then the rifle range of Whitlingham Park. [249 071]. Rowe Coll. [BMNH]: contains a superbly preserved associated group of Austinocrinus columnals [E46879] recorded by Rowe MS as Pentacrinus bronni.

**WHITLINGHAM**, west of the White House: virtually obscured sections in woodland [2656 0774]. BGS: CJW 2983-97.

About 0.50m chalk with Inoceramus sheets, belemnites and pink brachiopods overlying semi-continuous 10 cm thalassinoid flint; no paramoudras observed either in situ or loose. On the floor of the section were found blocks of very hard pale yellow chalk with glauconite-lined burrows, one such block possibly representing the indurated infilling of a large paramoudra. The author collected small Carneithyris carnea, small cuboidal Cretirhynchia ex gr. norvicensis, Belemnitella 'langei' and B.'posterior': this assemblage indicated a Paramoudra$_1$ horizon, which would correspond to the beds of this age exposed in the nearby Colman's pit [2678 0766] (pp.73-74).

**WHITLINGHAM:** Old Chalkpit Plantation [2701 0776]. Overgrown section exposing white chalk with a zone of thalassinoid flints. BGS: CJW 2969-82.

This section is near and may even have formed part of the smaller and more westerly of the two pits open at Whitlingham in the 1870s and recorded by Woodward (1882, p.80), although the area of disturbed ground immediately to the east at [2720 0774] is more likely.

The author's material includes Carneithyris carnea, Cretirhynchia transitional between C. arcuata and C. limbata; and indeterminate small bored belemnites.

**WHITLINGHAM:** degraded pit immediately W. of St. Andrew's Church ruins = larger of two pits recorded by Woodward (1882, p.80). [2734 0786]. BGS: CJW 2952-68.

The succession exposed by digging was closely comparable with that at Postwick Grove (p.76) in that orange-white mottled chalk overlay a 30-cm complex zone of large thalassinoid flints, and a bed of indurated chalk was present at the top of the section. However, this type of succession could be repeated several times in Paramoudra$_2$, and a definite correlation with Postwick Grove cannot be established at present. It was this pit which formerly displayed the tight anticlinal structure first recorded by Taylor (1865) and later figured and discussed by Woodward (1876, fig. 21; 1882), suggesting either that the Chalk had been subject to local glacial tectonics, or that it was actually part of a raft. In the latter case there need be no clear stratigraphical relationship with the other Whitlingham localities or with the pits on the opposite side of the river between Thorpe and Postwick Grove. In this context, it is interesting to note that Woodward's figure (which was drawn from a photograph) shows no paramoudras, but merely courses of irregularly elongated nodular flint.

The author's material includes *Cretirhynchia* transitional between *C. arcuata* and *C. limbata*; '*Aequipecten*' aff. *campaniensis*, pieces of thick-shelled *Inoceramus*, *Limatula* sp. and an incomplete *Echinocorys* ex gr. *belgica* matching material from Colman's pit. Also present were small, elongate, and comparatively well vascularised *Belemnitella* sp. of uncertain affinity, but possibly conspecific with forms from the Lower Maastrichtian Pre-*Porosphaera* and *Porosphaera* Beds of the coast.

Woodward material from this or the previous locality [BGS: HBW 241, 249-55, 365-6, 396] includes *Carneithyris carnea*, a large *Cretirhynchia* near *C. limbata* s.s. [HBW 254], medium-sized thin-shelled gryphaeate *Pycnodonte* (*Phygraea*), depressed dome-shaped variant of *Echinocorys* ex gr. *belgica* and a *Mosasaurus* tooth.

**WHITLINGHAM SEWAGE FARM:** temporary large excavation exposing Chalk overlain by shelly Norwich Crag [278 086]. Peak Coll: Goff Coll. [NCM]; BGS: CJW 5357-61.

Chalk with one or more zones of small thalassinoid burrow-form flints, but otherwise relatively flint-free; apparently very poorly fossiliferous; no detailed measured section available. Fossils were collected from the spoil by Mr. N.B. Peake, and also by Dr. J. Goff. Dr. Goff saw a temporary very deep pit in white chalk, but no section was measured. The orientation of the Chalk surface suggests that the whole succession here is part of a gigantic raft, particularly as till has been observed to dip beneath the Chalk at one end of the section.

The author's material comprises Cretirhynchia cf. arcuata, a fragmentary pycnodonteine oyster and Belemnitella 'langei'.

The Goff Coll. [NCM] includes 2 Echinocorys ex gr. belgica of uppermost Campanian type [comparable forms are known from the 'pryamidata-Conglomerate' of Overstrand which is developed at or near the Campanian-Maastrichtian boundary - see Peake and Hancock 1970, p.339G and 2 Micraster of the M. ciplyensis-grimmensis group, these being indicative of a Paramoudra$_2$ horizon. The Belemnitella from here are of uncertain affinity but probably belong to forms noted above under Whitlingham (St. Andrew's Church) pit. Taken together, the fauna points to a high or highest Upper Campanian rather than Lower Maastrichtian horizon for this locality, particularly as there is evidence that the Campanian-Maastrichtian boundary lies about 1.5 km further east in the vicinity of the Wood's End Inn, Bramerton.

**BRAMERTON:** excavation for gas pipeline west of Wood's End Inn at [291062]. No section was observed but material collected from the spoil by Dr. Goff included Echinocorys attributable to a high Upper Campanian position. This stratigraphical assignment would agree with the presence of proven Lower Maastrichtian about 0.5 km farther east (see p.99).

(vi) Yare valley east of Norwich (north side) from west to east

**THORPE - next Norwich** (Thorpe village): the positions of former pits can be identified behind houses at [2570 0868] and [2616 0862], but no Chalk or Norwich Crag is exposed. It is probable that one or other of these pits is the 'pit in the village of Thorpe' referred to by Woodward (1882, p.75, ex S. Woodward 1825 MS) which exposed some 12m of Chalk beneath Norwich Crag, and material labelled 'Thorpe' in very early collections may have come from here rather than from the pits to the east of the village, i.e. Thorpe Limekiln pit and Thorpe Tollgate pit.

A temporary section behind a block of flats [2570 0845] immediately to the south of the first of the Thorpe village pits exposed Glacial Sand and Gravel channelled into yellow Chalk: a small collection from here made by the author [CJW 2937-47] included a large Porosphaera sp., small Carneithyris carnea, Cretirhynchia ex gr. norvicensis [juv], Belemnitella 'langei' and a giant form exhibiting transitional characters between the B. mucronata sensu Jeletzky of the Beeston Chalk and the B. 'posterior' which characterises Paramoudra$_1$ and above.

**'THORPE ST. ANDREW'S PIT'** = Thorpe Asylum pit or Thorpe (Lime)kiln pit. [2755 0900]. Rowe loc. 153. Old collections [NCM] Rowe [BMNH with symbol T]: very large collection, mainly echinoids; also moulds of small gastropods from hard chalk and from the chalk infilling of large echinoids (circa 100); BGS: HBW 293-306, 367-74, 421-4, 428-9; CP 185-216; Hs 499-605; Zf 1598-1629 and Ze 2843-2860, both ex J.H. Capon Coll. [mainly small gastropods comparable to the Rowe material]; CJW 2914-36.

This is the pit described by Woodward (1882, pp.73-4) as "immediately west of the Cromer branch railway"; the section (ibid. p.74, pl.3, fig. 1) in 1875 exposed 6m of Chalk with flints and paramoudras beneath Norwich Crag. Woodward also mentioned a pit "to the west of the kiln", which can be identified as the overgrown area (Townpit Plantation) on the west side of Pound Lane at [2740 0897]; and a pit "a little further east (near the Toll-gate)" which is considered below.

Rowe MS: "Echinocorys [13 E. ex gr. belgica: E34968-80], very large and with very thick tests in a band about middle of section all round pit. Micraster and Epiaster [21 Micraster ciplyensis: E19732-8; 19744-6; 19755-65] found throughout the 14′ [4.2m], but there is a thin band at top of adit in the Brachylepas section, from which we have obtained 10, whole or broken in a space of 4′ [1.2m]. The S.(erpula) complanata is v. common here. T. carnea v. abundant ... 14 ft [3.2m] of chalk about 6′ [1.8m] of hard bands ... (1911) now a miniature rifle range at entrance end but worked recently at far end. Many pseudoparamoudras and one moniliform series. 4′ [1.2m] exposed. Chalk heavily stained with Fe and Mn."

The fauna of the Thorpe Asylum pit has already been discussed under Paramoudra$_2$ (p.39); Rowe has an extensive MS list. This pit provided the holotypes of Sahni's terebratulid taxa Carneithyris uniplicata, C. ornata and Magnithyris magna [BGS: all ex HBW Coll]. Much unlocalised sponge and ammonite material in NCM may have come from the 'hard bands' noted by Rowe. No section is currently visible, but the section previously exposed yielded to the author small Carneithyris carnea, poorly preserved belemnites and Micraster ciplyensis.

**THORPE TOLL-GATE PIT.** [2830 0894]. BGS: CJW 2914-47.

The third and most easterly of the three pits east of Thorpe village recorded by Woodward (1882) is here taken to be the marl pit shown on the Old Series 1" Geological map to the north of the Toll-gate.

This is the pit from which Fitch (1836) recorded the discovery of a Mastodon tooth in the Norwich Crag, and it may well be the source of a certain amount of Chalk material in old collections labelled 'Thorpe'. There is clear evidence of a former pit of considerable size, but it is now virtually obscured by rubbish apart from about 1m of Chalk preserved beneath a tree in the deepest part of the pit: the chalk is markedly yellow as at Thorpe Asylum pit and includes a hard bed with poorly preserved sponges and baculitids above and below a thalassinoid flint. The chalk is extremely fossiliferous. It is probably stratigraphically equivalent to Postwick Grove and slightly younger than Thorpe Asylum.

Fossils collected by the author include: Coscinopora sp., hexactinellid indet., Aphrocallistes cylindrodactylus, Carneithyris carnea, Cretirhynchia ex gr. arcuata, Terebratulina chrysalis, Chlamys aff. denticulata, Limatula decusssata, Neithea sexcostata, large, thick-shelled, gryphaeate Pycnodonte, indeterminate (aragonitic) trochid gastropods, bivalves and a scaphopod preserved as moulds, Belemnitella cf. 'langei'.

**BANKS OF YARE DOWNSTREAM OF POSTWICK GROVE** [2869 0768]. BGS: CJW 5399-402.

Intermittent river beach exposures of Chalk may be seen occasionally at low water. Mr. Peake reports [pers. comm.] the occurrence of brachiopods [Goff Coll: NCM] and Micraster of the ciplyensis-grimmensis group. The top of the (disturbed) Chalk section was observed by the author just above water; no flints were seen in situ but overgrown thalassinoid flints, presumably freshly derived, were lying nearby on the beach. It is of interest that the chalk here is white rather than yellow as at Postwick Grove and the Thorpe Tollgate and Asylum pits. The author collected Pycnodonte (Phygraea) sp. and an indet. belemnite.

### C. The Belemnella lanceolata Zone

**BRAMERTON,** south bank of River Yare, west of Hill House: [2956 0609]. BGS: CJW 2837-81

Erosion of the bank and river beach at this point exposed the following section in ascending order:

(1) Hard yellow chalk surrounding a large, complex, up to 25-cm nodular flint: (2) rounded thalassinoid burrow-form flints with white cortex incorporating oysters, terebratulid brachiopods and other small

fossils; (3) slightly yellow gritty hard chalk with terebratulids. The whole section was only just above water level and was consequently difficult to measure in detail.

The following fauna was collected:

(1) *Aphrocallistes cylindrodactylus*, *Ditrupa* sp., *Carneithyris carnea*, *Cretirhynchia* near *arcuata*, *C*. ex gr. *norvicensis* [cuboidal form], *C*. cf. *magna*, *Kingenella* sp?, *Neoliothyrina* sp., *Orbirhynchia* sp, small plicate oyster provisionally recorded as *Margostrea* aff. *alaeformis*, *Belemnitella* sp. juv. cf. '*posterior*', *Echinocorys* ex gr. *belgica* [small pyramidate flat-based form with symmetrical profile]; (2): *Ditrupa*, *Carneithyris carnea*, plicate oyster as in (1), *Echinocorys* ex gr. *belgica* including giant forms up to 100 mm long comparable with those occurring in the Lower Maastrichtian of Sidestrand; (3): *Carneithyris carnea*, *Cretirhynchia* near *arcuata*, *Belemnitella* sp. juv. cf. '*posterior*' and an alveolar fragment of this species.

Although no specimens of the diagnostic Lower Maastrichtian belemnite genus *Belemnella* were found at the time, it is reported that subsequent dredging operations brought up large quantities of chalk from the river bed and that local schoolboys collected belemnites including *Belemnella*. Terebratulids from this locality still retain the pink colouration characteristic of material from Upper Campanian sediments and were assigned to the Campanian species *Carneithyris carnea* by Asgaard (1975) on the basis of the structure of the cardinalia, rather than to the Maastrichtian species *C*. *subcardinalis* (Sahni); 8 specimens from the CJW collection were used by Asgaard in her statistical analysis of a 'Bramerton' population. Bramerton specimens of *Carneithyris*, in common with those from Thorpe Asylum pit, were noted by Asgaard to exhibit a tendency to incipient uniplication or paraplication of the commissure.

Whittlesea (1985a) recorded the fauna from a trench section at Bramerton which ran from the extreme eastern end of the Common [297 061] to about 100m west of the Woods End Public House. Chalk excavated from the eastern end of the trench was markedly yellow and rich in Zoophycos. Much of the chalk came from a hardground and contained numerous hexactinellid sponges. Whittlesea recorded 6 Belemnitella sp., which he inferred to be Campanian, although they could equally well have had a Lower Maastrichtian provenance.

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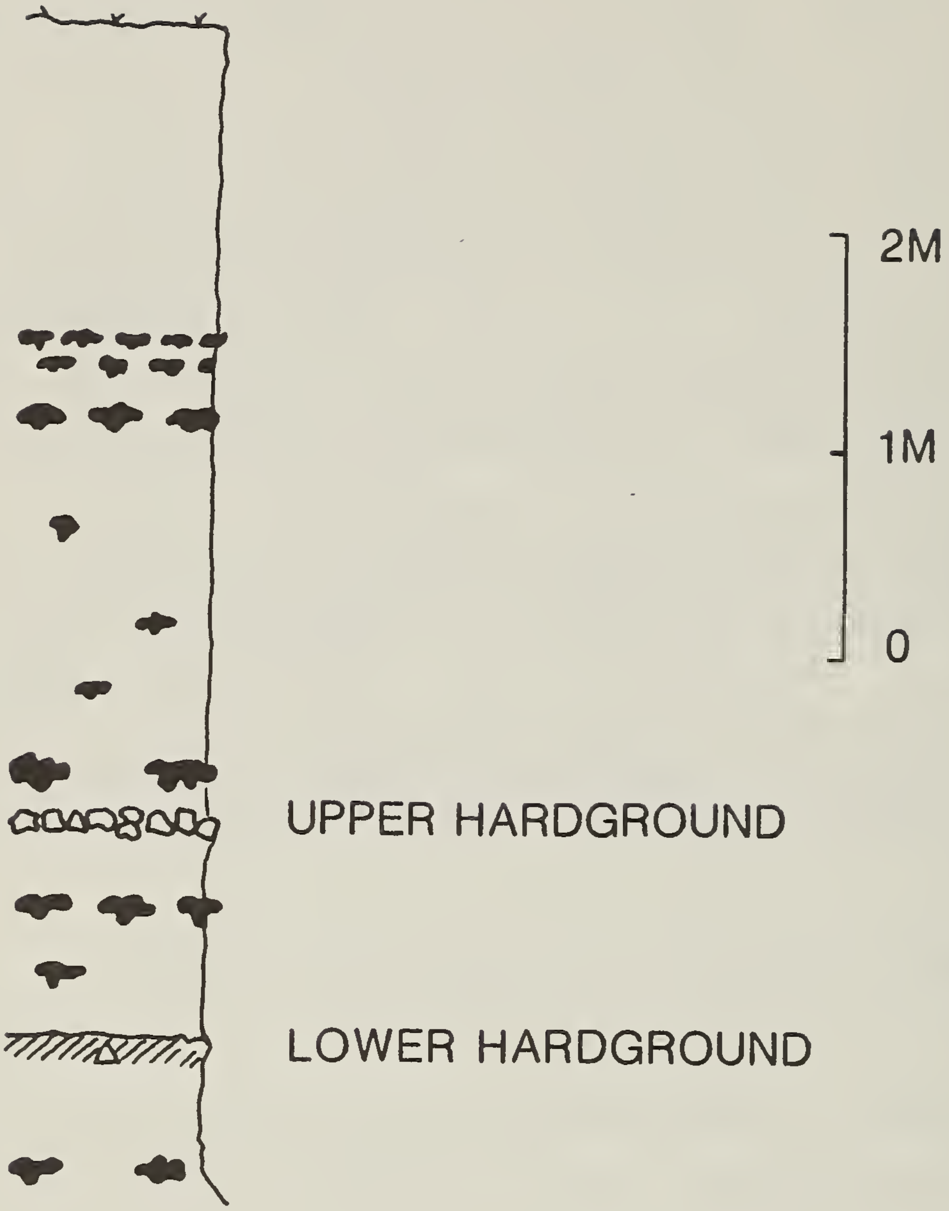


Fig.1 Section in the Upper Chalk of the Bowthorpe Hall sewer trench. (1789 0905 - 1768 0913)

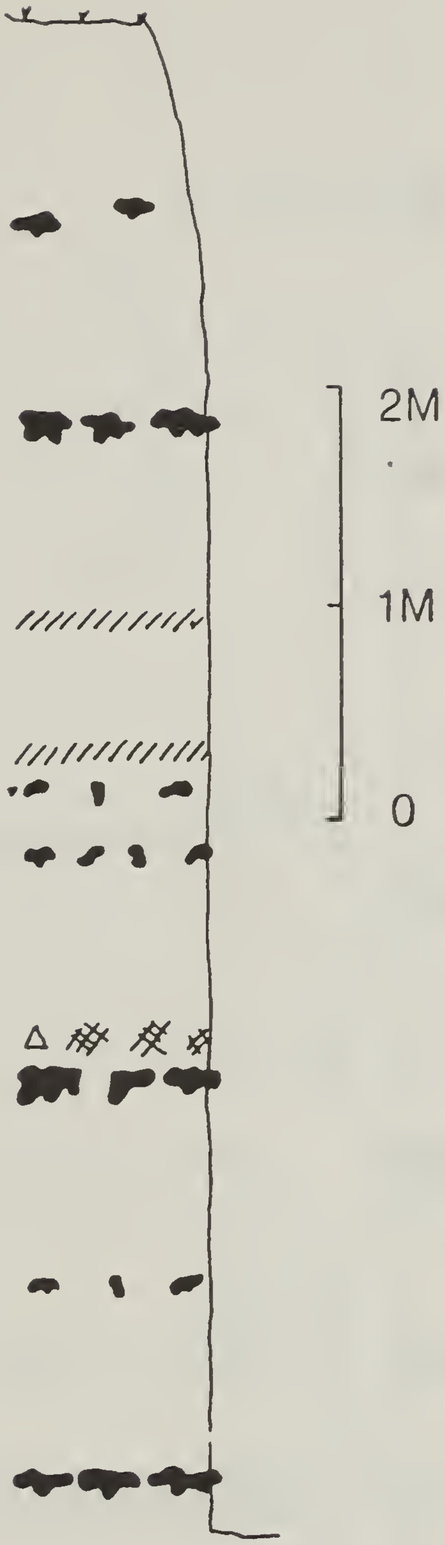


Fig.2 Section in the Upper Chalk of the Cringleford By-pass. (1965 0590)

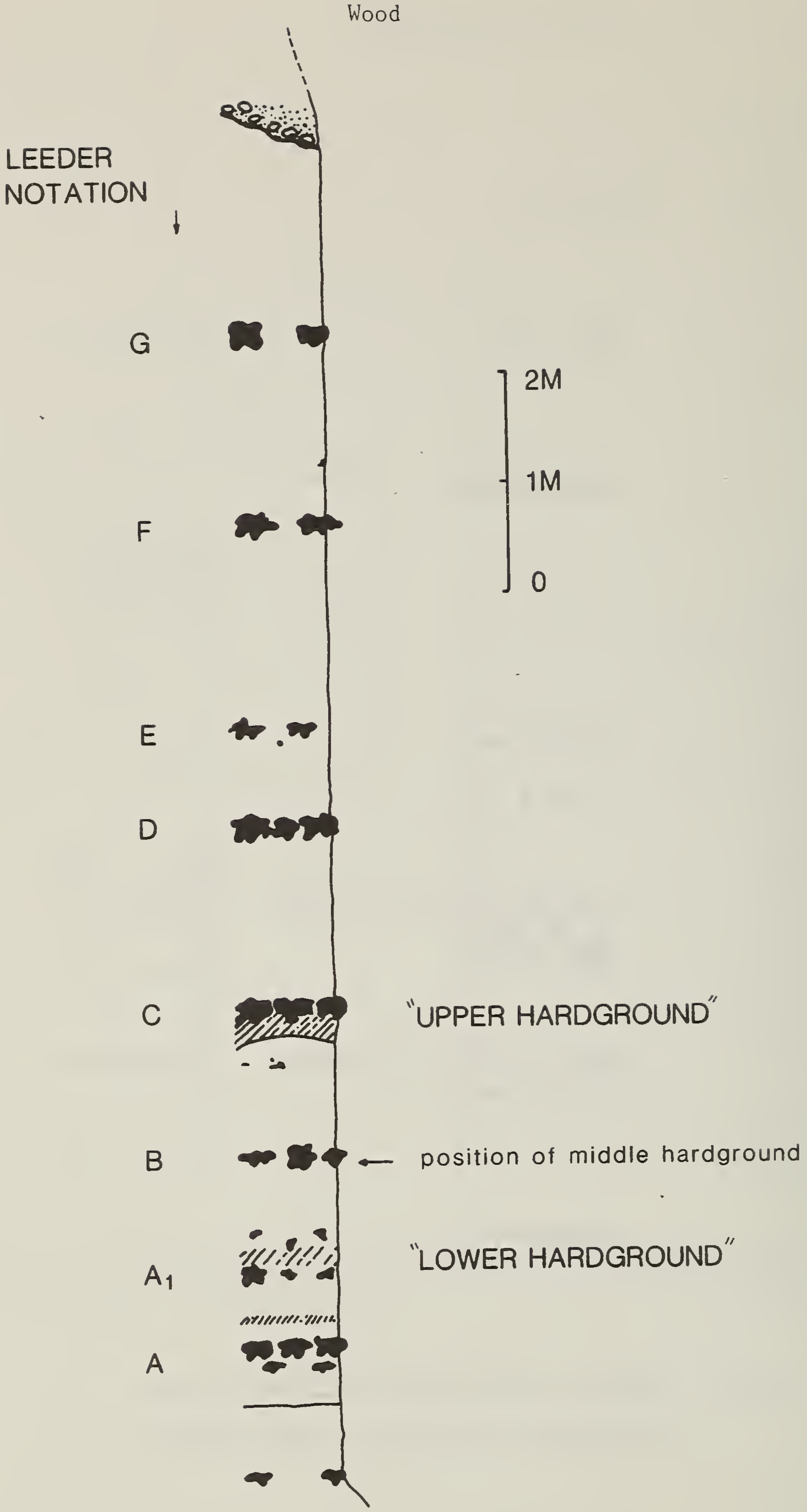


Fig.3 Section in the Upper Chalk of the Eaton Limeworks. (208 063)

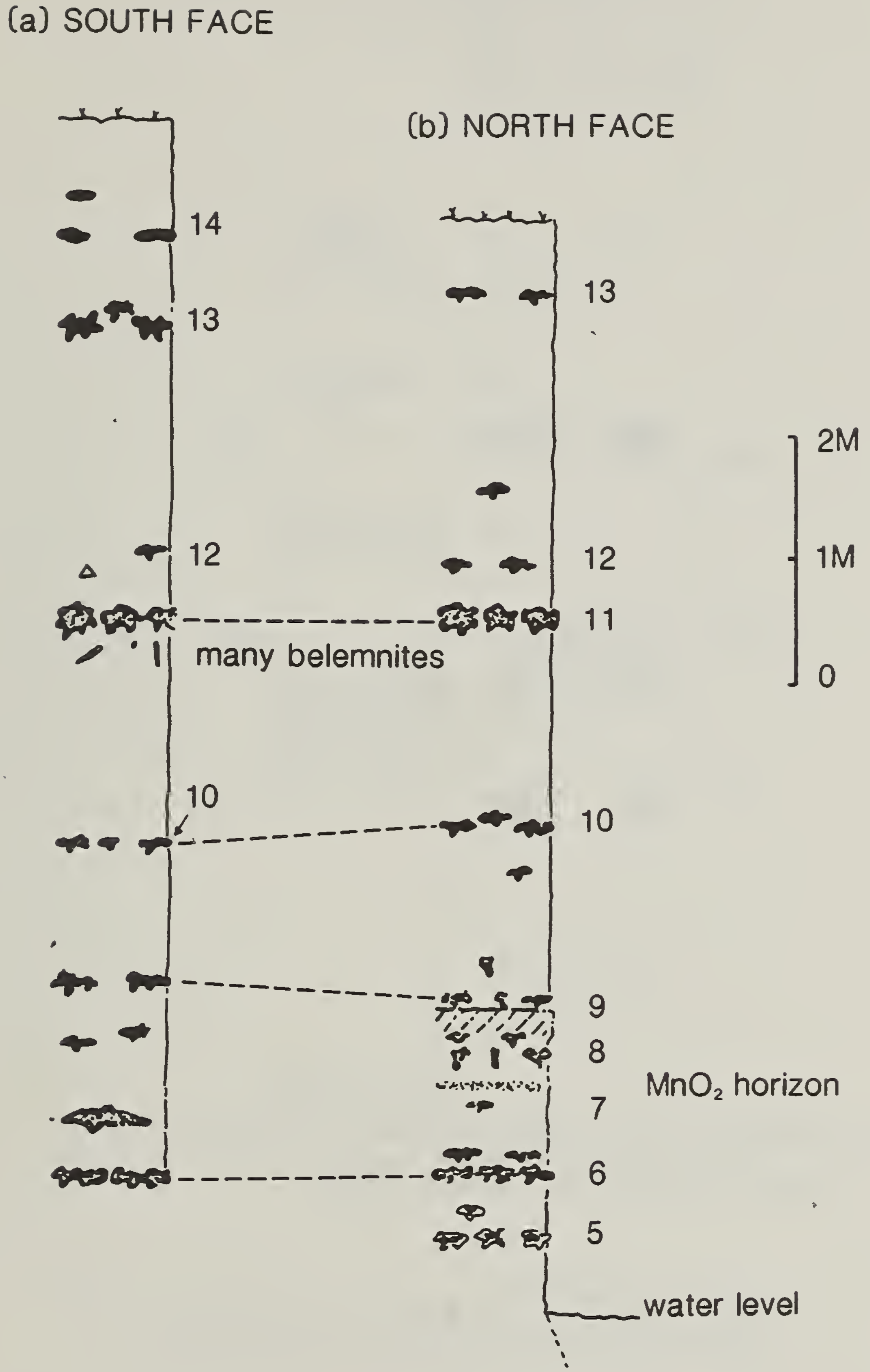


Fig.4 Sections in the Upper Chalk of the Keswick Chalk Pit (212 048)

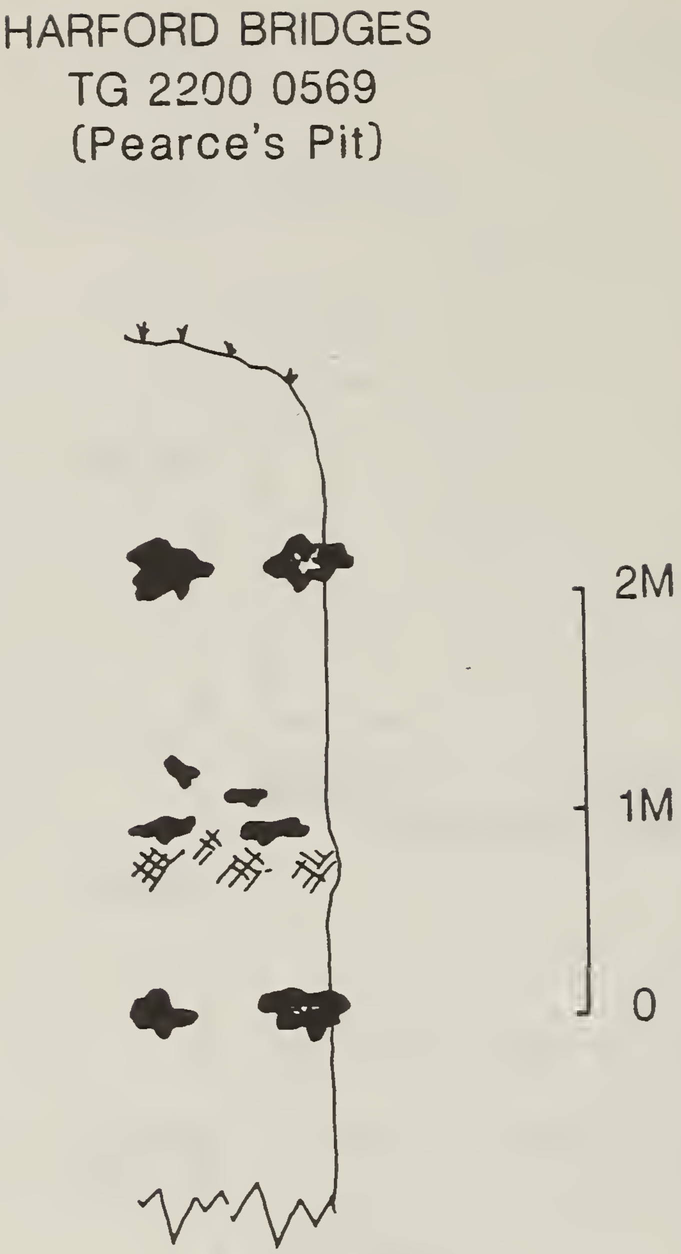


Fig.5 Section in the Upper Chalk of Pearce's Pit, Harford Bridges. (2200 0569)

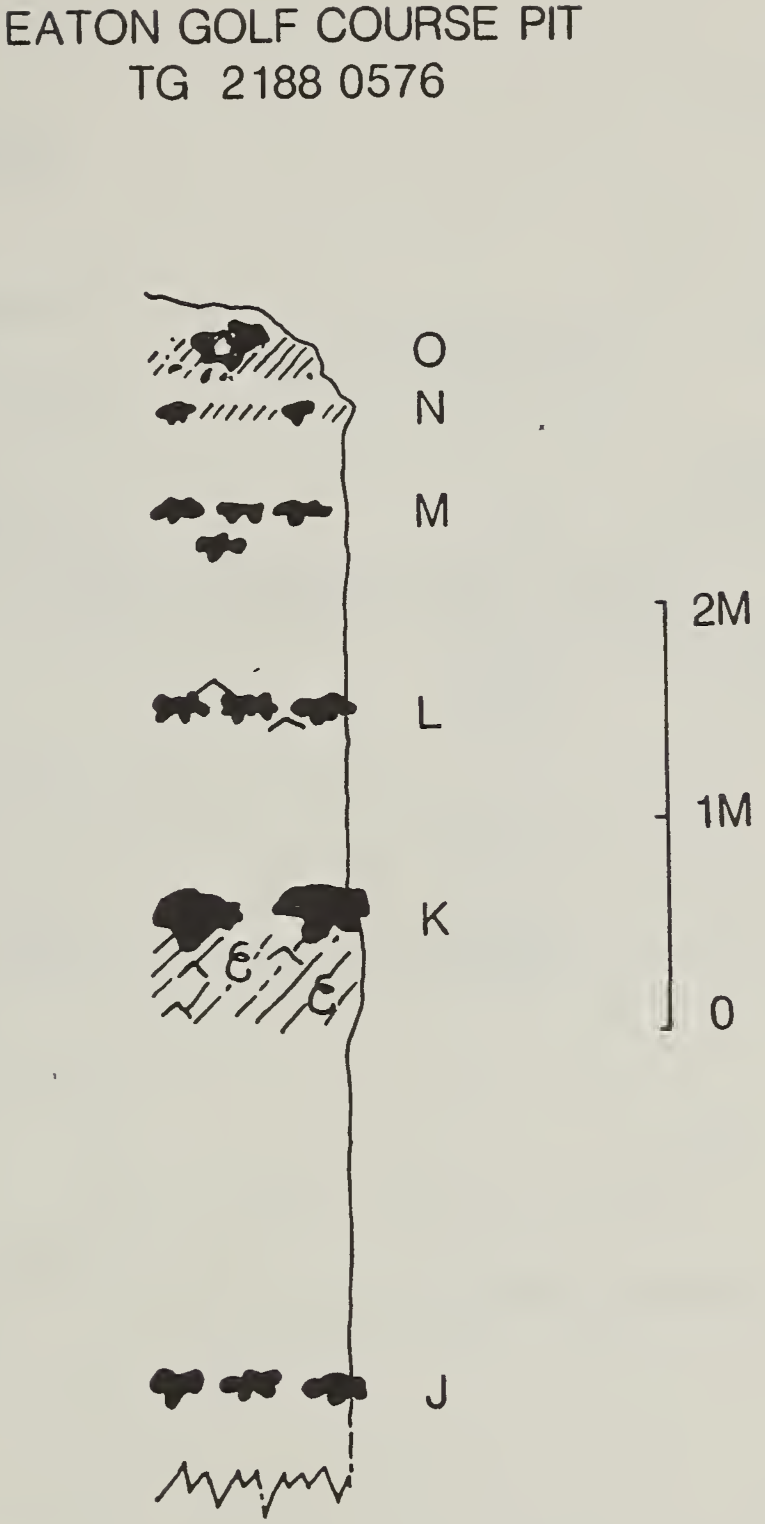
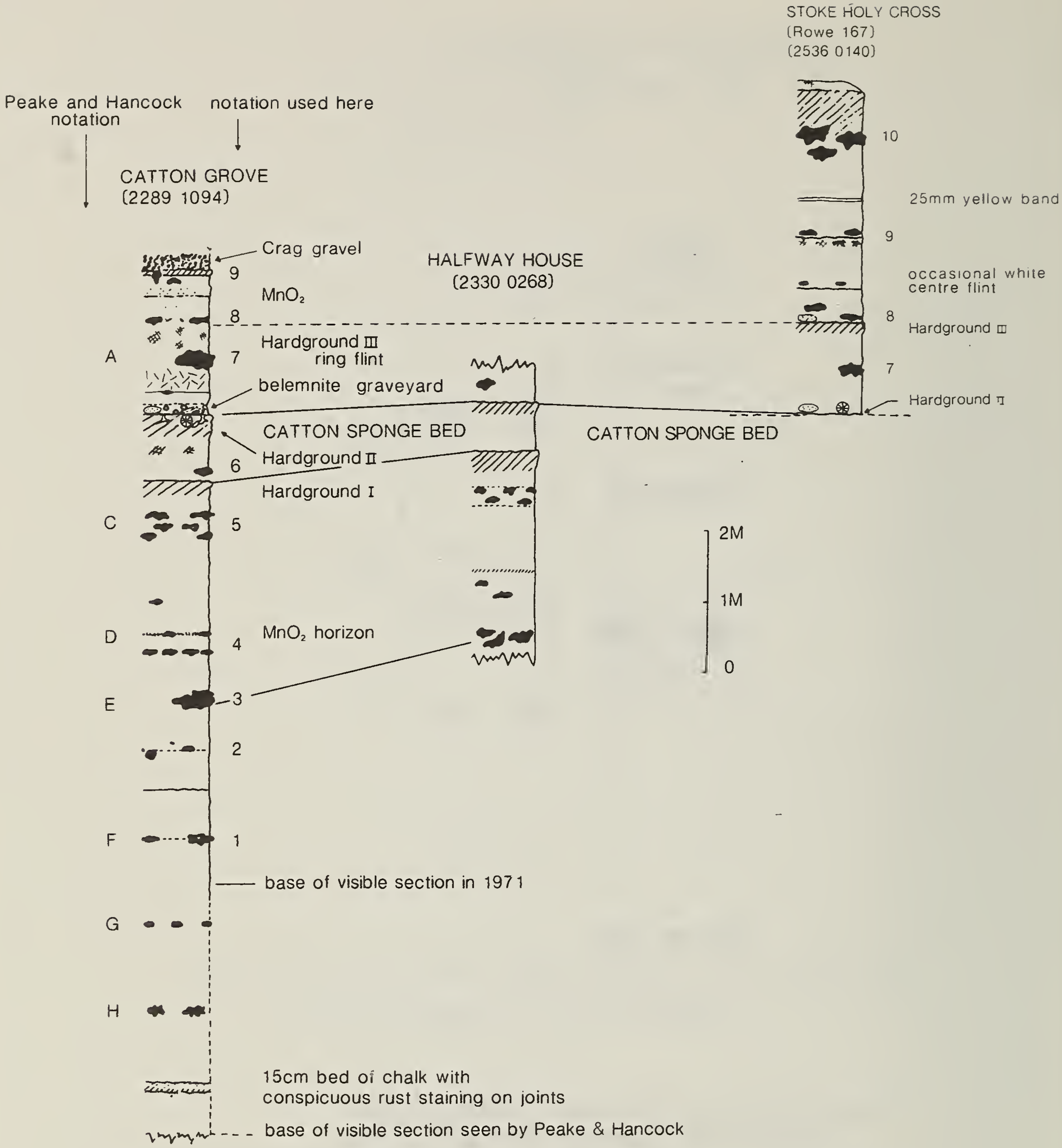


Fig.6 Section in the Upper Chalk of the Eaton Golf Course Pit (2188 0576)



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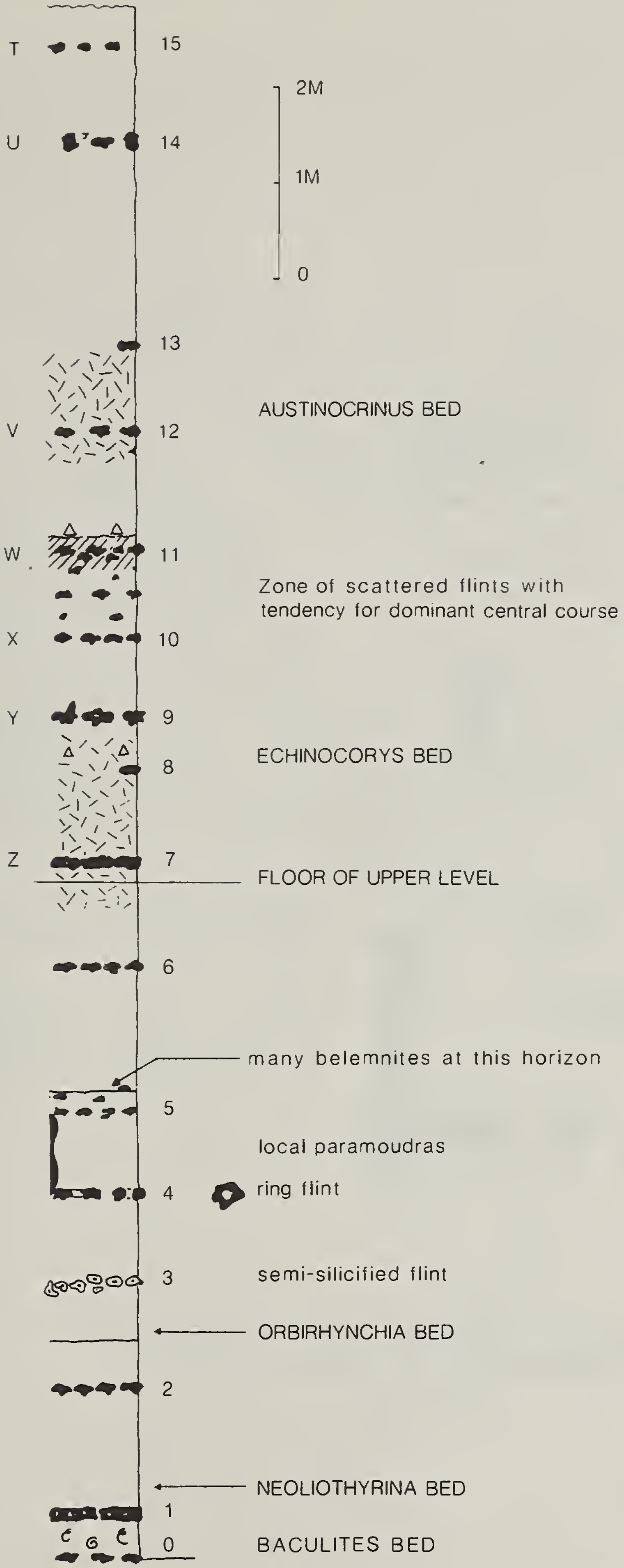

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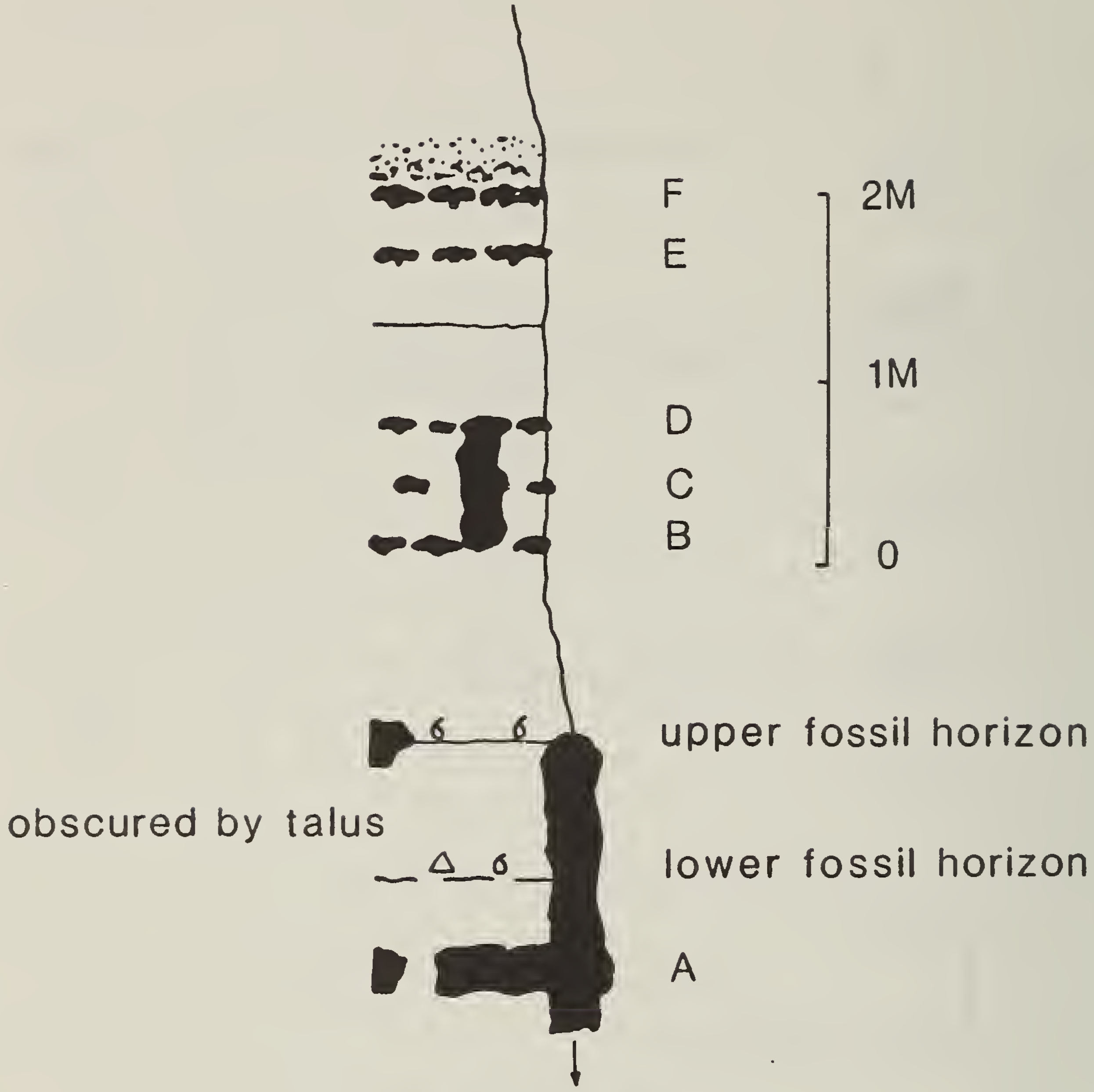

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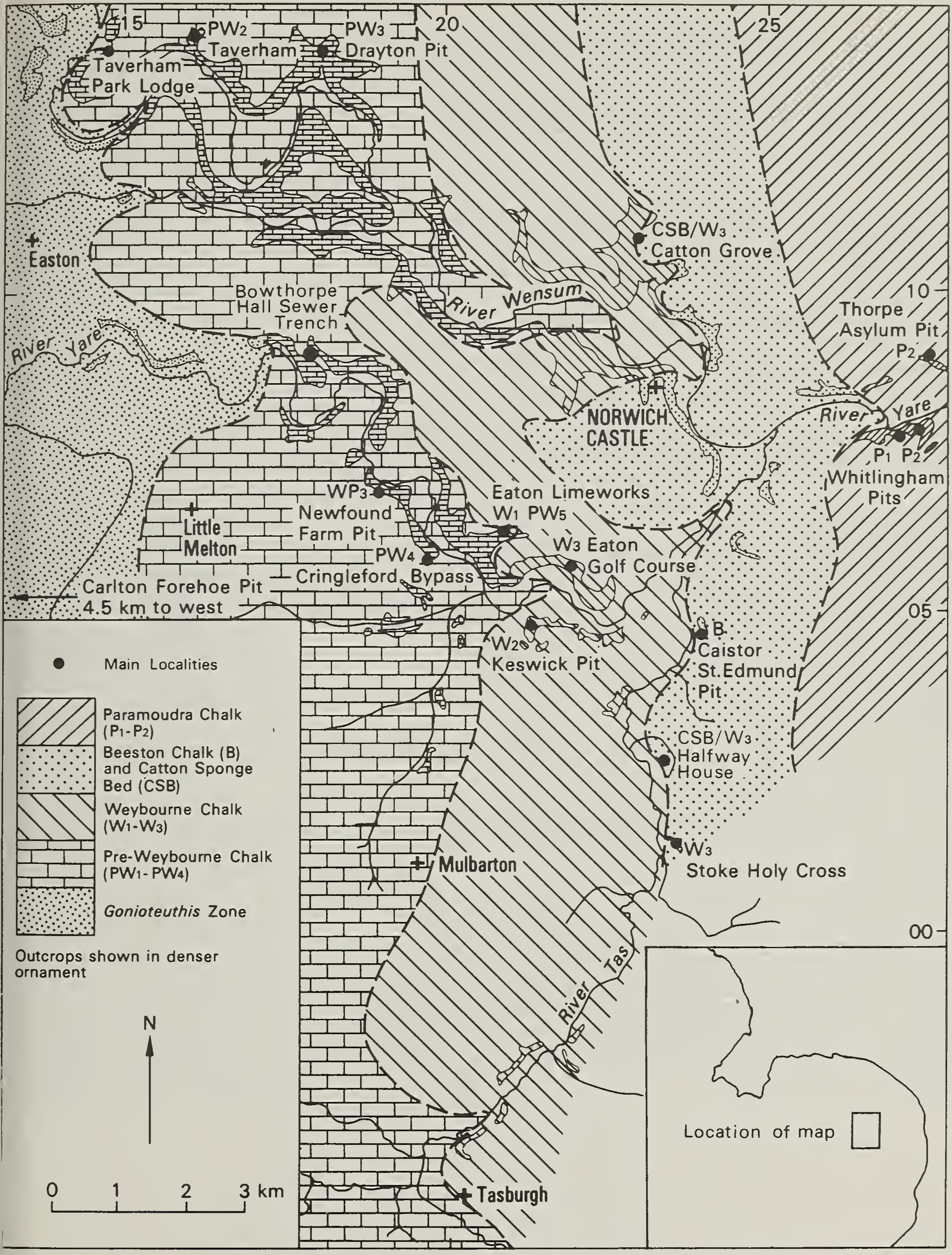
Map of Localities and Chalk zones referred to in the text



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# HERPETOFAUNA OF THE WEST RUNTON FRESHWATER BED (MIDDLE PLEISTOCENE; CROMERIAN INTERGLACIAL), WEST RUNTON, NORFOLK

J.Alan Holman*, John D. Clayden+ and Anthony J. Stuart^

## ABSTRACT

The West Runton Freshwater Bed (Middle Pleistocene, Cromerian Interglacial) at West Runton, Norfolk, has yielded a rich fossil vertebrate assemblage. The mammals, which are the must abundant, have received most attention, whereas the herpetofauna (amphibians and reptiles) has been almost neglected since the last century. Taxa identified on the basis of material obtained so far from sieving this bed include: common newt Triturus vulgaris, a newt Triturus sp. indet., common toad Bufo bufo, a toad Bufo sp. indet., moor frog Rana arvalis arvalis, edible frog Rana "esculenta" or marsh frog Rana ridibunda, common frog Rana temporaria, a frog Rana sp. indet., slow worm Anguis fragilis, grass snake Natrix natrix and adder Vipera berus. Of these R. a. arvalis and R."esculenta"/ridibunda no longer occur native in Britain.

## INTRODUCTION

British Middle Pleistocene amphibians and reptiles, other than European pond tortoise Emys orbicularis (Stuart 1979, 1982) have been given little attention since the late 19th century (Newton 1882a, b). Yet, without studies of the herpetofauna, knowledge of biotic responses of the British vertebrate fauna to the environmental changes of the Pleistocene is incomplete. Moreover, because the present

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distributions of herpetofaunas are largely a factor of climate, the study of such fossil records is a valuable potential source of information for climatic conditions at various times in the Pleistocene.

Recently we were able to study fossil amphibian and reptile remains from the type Cromerian deposits (part of the Cromer Forest-bed Formation) at West Runton, Norfolk. The collections are housed at the British Museum (Natural History), the University Museum of Zoology, Cambridge, the Castle Museum, Norwich, and the private John D. Clayden Collection at East Runton, Norfolk.

*Cromer Forest Bed Formation* The Cromer Forest Bed Formation (CF-bF), which comprises a complex series of both freshwater and marine deposits, crops out at intervals along the coast of eastern Norfolk and part of north-east Suffolk. These deposits, long famous for their wealth of fossil mammal remains, were studied in detail by West (1980a). West showed, on the basis of fossil pollen assemblages, that the deposits cover several major climatic oscillations between cold and temperate conditions, viz. (in order of decreasing age) the Pre-Pastonian, Pastonian, Beestonian and Cromerian Stages of the Lower and Middle Pleistocene. Of these the Pastonian and Cromerian are temperate stages and the others cold. The Cromerian temperate stage, or interglacial, in turn gave way to cold conditions with the onset of the succeeding Anglian Cold Stage, within which occurred the most extensive glaciation of Britain, and the CF-bF is capped by Anglian tills and outwash deposits.

*West Runton Freshwater Bed* The West Runton Freshwater Bed has produced by far the richest vertebrate fauna of any non-cave site in Britain (Newton 1982a, b; Hinton 1926; Stuart 1975, 1982). It is exposed at the base of the cliff east of West Runton Gap (Woman Hythe), has a maximum thickness of 2 metres and occupies a broad channel about 300 metres long cut into mainly marine sands and gravels of earlier Pleistocene stages. The Freshwater Bed comprises sand, silt and organic muds rich in molluscan shells, wood and other plant detritus. Overlying the Freshwater Bed is a thin estuarine gravel, followed by marine laminated silts and sands about 5 metres thick. Above these come sands deposited in freshwater, succeeded by tills and outwash sands and gravels which constitute the upper part of the cliff. Details of the stratigraphy, pollen and plant macrofossil assemblages, and non-marine mollusca are in West (1980a, b). The Freshwater Bed and overlying marine deposits together represent an entire early Middle Pleistocene interglacial cycle; and these deposits were designated the stratotype for the Cromerian Interglacial (Mitchell et al. 1973). The sequence of pollen assemblages records regional vegetational changes from pine-birch woodland (substage I) to mixed oak forest (substage II), mixed oak forest and silver fir (_Abies_) and hornbeam (_Carpinus_) (substage III), and birch-conifer forest (substage IV). The same broad sequence is recorded from each interglacial stage, but each has its own unique vegetational characteristics (West 1980b). The majority of the vertebrate fossils and all of the fossil herpetofauna came from substages Ib to IIb of the Freshwater Bed (Stuart 1982). The vegetation during substage Ib was predominantly pine-elm-birch woodland with extensive herb vegetation giving way to largely deciduous forest with oak and other temperate trees in substages IIa to IIb. Fen and reedswamp plants are well represented by fossil remains and areas of herb vegetation persisted in an otherwise forested environment.

Institutional Sources of Fossil Material (1) Fossil vertebrate material, including some herpetofaunal remains, from West Runton was collected by A.C. Savin of Cromer, Norfolk, in the late 19th and early 20th centuries. Much of this material is in the palaeontological collections of the British Museum (Natural History), but there are also important finds at Norwich Castle Museum (see below).

(2) Material in the University Museum of Zoology, Cambridge, was collected by A.J. Stuart from 1968-1970 from near the eastern limit of the deposit close to Goss' Gap, east of West Runton Gap (Stuart 1975, 1982; West 1980a). For the purpose of collecting small vertebrate fossils the fossiliferous part of the bed, some 0.8 metres thick (omitting the topmost leached horizon), was divided vertically intc three units, A, B. and C (Stuart 1975). The basal unit A comprised reworked marl clasts, and pebbles of flint and quartz in a matrix of sand, silt and clay with some plant detritus. Unit B was transitional, with a much higher proportion of organic mud and smaller clasts, and unit C consisted mainly of detritus mud with sand, silt and clay. All units were rich in non-marine molluscan shells. Thirteen sediment samples of about 20-25 kg each, collected from each of these units, were processed for small vertebrate fossils by wet screening through a 1 mm sieve and drying and sorting the concentrate.

(3) Material in the Norwich Castle Museum was collected by A.C. Savin before 1945. A small amount of additional material was collected in the 1980s by J. Goldsmith and others.

(4) The remainder of the material described here was collected by John D. Clayden and is at present in his private collection at East Runton, Norfolk, where it is available for study. All of the fossils were obtained by sieving the lower brecciated unit of the West Runton

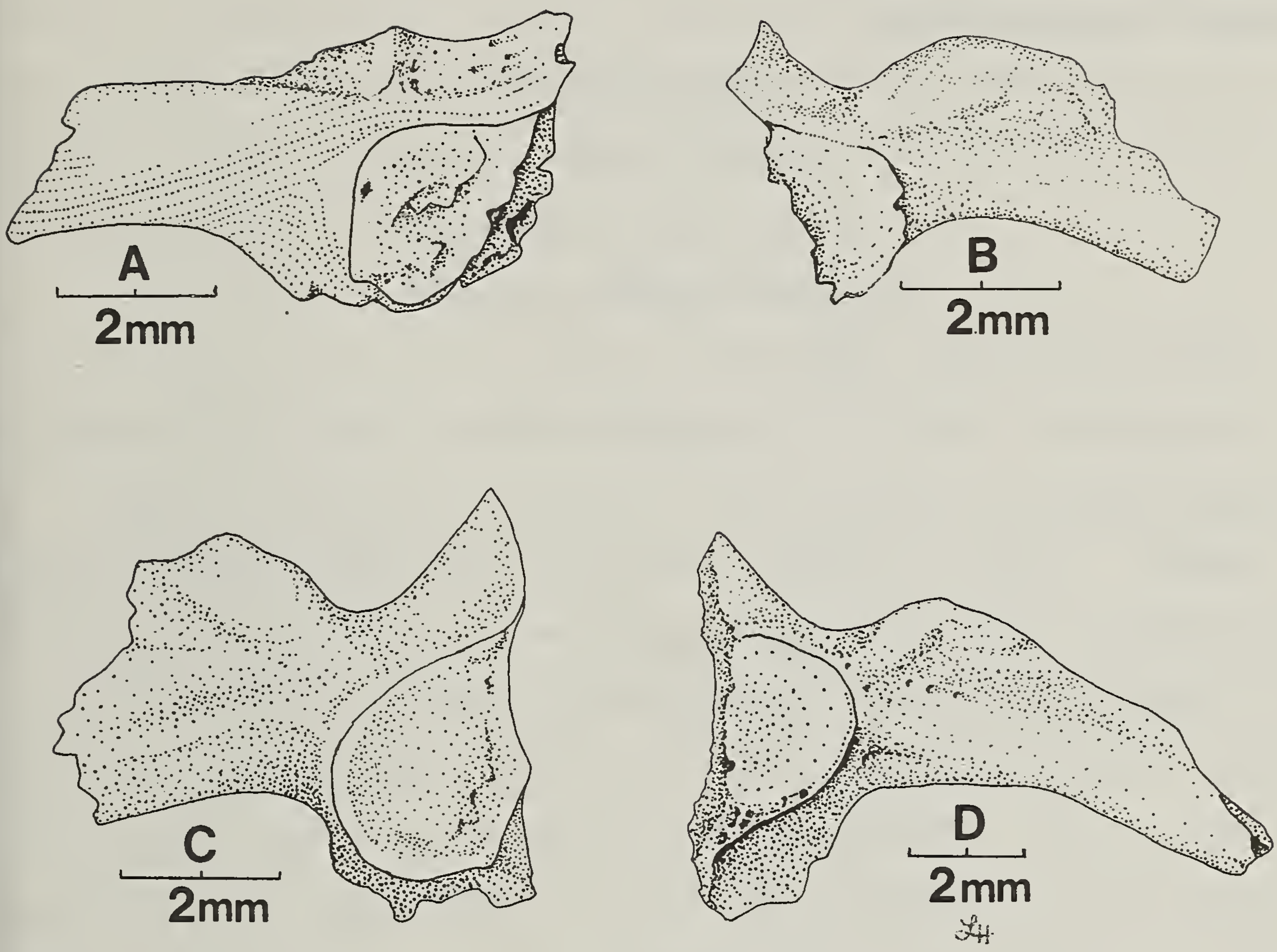

Figure 1. (A) Fossil left ilium of *Bufo bufo*, John D. Clayden Collection No. JCWR 3. (B) Fossil right ilium of *Rana arvalis arvalis*, John D. Clayden Collection No. JCWR 8. (C) Fossil left ilium of *Rana* "*esculenta*" or *ridibunda*, John D. Clayden Collection No. JCWR 10. (D) Fossil right ilium of *Rana temporaria*, John D. Clayden Collection No. JCWR 15.

Freshwater Bed (Bed f of West 1980a, equivalent to unit A of Stuart 1975). The precise localities from which specimens were obtained are designed by e.g. '168-172' which indicates the distance in metres along the Freshwater Bed measured eastwards from the datum at West Runton Gap (see West 1980a).

## SYSTEMATIC PALAEONTOLOGY

### Class Amphibia

### Order Caudata

### Family Salamandridae

### *Triturus vulgaris* Linnaeus

*Previous Material* None

*New Material* John D. Clayden Collection: JCWR 1-2 from 168-172, two vertebrae.

*Remarks* Based on modern skeletons, *Triturus vulgaris* may be distinguished from other *Triturus* species on the basis of individual trunk vertebrae. In *T. vulgaris* the postzygapophyseal notch is narrower and more deeply indented than in *T. helveticus*. The trunk vertebrae of *T. vulgaris* may be distinguished from those of *T. cristatus* and *T. marmoratus* in having a much higher neural spine, and in being smaller than in both species. This is the first time this species has been reported as a fossil in Britain, although Böhme (1979) has reported it from the upper Pleistocene of eastern Germany. This species occurs in the area today (Frazer 1983).

### *Triturus* sp. indet.

*Previous Material* A single un-numbered femur (Newton 1982a, b).

*New Material* None.

*Remarks* E.T. Newton (1982a) lists a single femur which he identified as *Triturus cristatus*. J.A. Holman has been unable to locate the specimen, but would agree that the figure (1882a, Pl.17, Fig.9) is that of the femur of a _Triturus_. Nevertheless, Newton was not aware at that time that there were three species of newts found in Britain, and one cannot be certain what forms were represented in his comparative specimens. Therefore, it seems best to consider this record as _Triturus_ sp. indet. until the original fossil can be found and compared with osteological material of at least all three of the modern British species, all of which occur in East Anglia today (Frazer 1983).

### Order Anura

### Family Bufonidae

### _Bufo bufo_ (Linnaeus)
(Fig. 1A)

_Previous Material_ Several miscellaneous elements including a left ilium (Newton 1882a, b).

_New Material_ John D. Clayden Collection: JCWR 3-6 from 168-172, three left and one right ilia. A.G. Savin Collection: BM(NH): R-6733, one left and five right ilia; R-6735, three left ilia; R-10186, one right ilium; R-10190, three left and one right ilia; R-10192, three left and four right ilia. A.J. Stuart Collection, UMZC: WR 573, left ilium from Sample A32: WR 746, right ilium from Sample A39; WR 1306, left ilium from Sample B 24.

This is a minimum number of 16 individuals based on a total number of 16 left ilia.

_Remarks_ Böhme (1977) and Holman (1985) discuss characters that enable one to identify individual fossil ilia of _Bufo bufo_, which has a low, sometimes roughened ilial prominence, from other British and Continental species. Newton (1882a, b) lists _Bufo_ sp. from the West Runton Freshwater Bed. His figure (1882a, Pl.17, Fig.8) is from a left ilium that may now be assigned with confidence to *Bufo bufo*. Th dorsal prominence of this specimen is low and roughened. *Bufo bufo* a well as *Bufo calamita* are found in East Anglia today (Frazer 1983) It seems noteworthy that the very distinct ilia of *B. calamita* hav not been found in the West Runton Freshwater Bed, even after years o collecting.

### *Bufo* sp. indet.

*Previous Material* A left ilium, previously assigned to *Bufo* sp by Newton (1882a) has been assigned to *Bufo bufo* (see above).

*New Material* A.G. Savin Collection BM(NH): R-6718, two sacra vertebrae. A.J. Stuart Collection UMZC: WR 37, sacral vertebra fro Sample A2: WR 601, sacral vertebra from Sample A33; WR 806, righ humerus from Sample B3.

This is a minimum number of four *Bufo* sp. indet. based on fou sacral vertebrae.

*Remarks* Sacral vertebrae of *Bufo* are easily separated from thos of *Rana* and other European genera in (1) being free from the urostyle (2) in having moderately dilated rather than cylindrical sacra diapophyses, (3) and in having an anteriorly directed and tw posteriorly directed condyles. Humeri of *Bufo* can be distinguishe from most *Rana* on the basis of having the distal surface of the dista humeral condyle flatter. These elements probably represent *Bufo bufo* but they are not as anatomically distinct from the other Europea species of *Bufo* as are the ilia.

### Family Ranidae

### *Rana arvalis arvalis* Nilsson

(Fig. 1B)

*Previous Material* None.

*New Material* John D. Clayden Collection: JCWR 7-9 from 168-172 two left and one right ilia. A.J. Stuart Collection UMZC: WR 660, left ilium from Sample A38.

This is a minimum number of three individuals based on three left ilia.

*Remarks* The ilium of *Rana arvalis arvalis* is diagnostic (Böhme 1977). The ilium of *R. a. arvalis* may be separated from *R. temporaria* and *R. graeca* in having a much better developed vexillum (ilial blade). The ilium of *R. a. arvalis* may be distinguished from the "water frogs", *R. ridibunda*, *R. "esculenta"*, and *R. lessonae*, on the basis of having a much more slender junctura ischiadica (see Böhme 1977, p.297, Fig.11b, g). Finally, *R. a. arvalis* may be distinguished from *R. dalmatia* and *R. latastei* in having the dorsal border of the vexillum (ilial blade) sloping downward rather than upward from the tuber superior (compare Figs. 9d, e with Figs. 9h, i in Böhme 1977, p.295).

*Rana a. arvalis* is separable from *R. a. wolterstorffi* on the basis of the smoother tuber superior in *R. a. arvalis* (Böhme 1977, p.295, Figs. 9d, e).

This is the second time this frog has been reported from the Pleistocene of Britain, the first report being form the Ipswichian of the Swanton Morley Site, Norfolk (Holman 1987). *Rana a. arvalis* does not occur naturally in Britain today, but occurs in the adjacent low countries of the Continent (Arnold and Burton 1985, p.258, map 37).

### *Rana "esculenta"* or *ridibunda*
(Fig. 1C)

*Previous Material* None.

*New Material* John D. Clayden Collection: JCWR 10 from 173-177, left ilium; JCWR 11-12 from 168-172, two right ilia. A.J. Stuart Collection UMZC: WR 661, right ilium from Sample A38; WR 1307, left ilium from Sample B25.

This is a minimum number of three individuals based on three right ilia.

*Remarks* Characters for distinguishing the "water frog" group of *Rana* on the basis of the ilium have been discussed in the preceeding section on *R*. *a*. *arvalis*.

Among the "water frogs", the ilia of *R*. *ridibunda* and *R*. "*esculenta*" (*R*. "*esculenta*" is a hybrid form of *R*. *ridibunda* x *R*. *lessonae* may be distinguished from *R*. *lessonae* on the basis of the following ilial characters. In *R*. *ridibunda* and *R*. "*esculenta*" the tuber superior is laterally flattened and lies in front of the anterior edge of the acetabular cup. In *R*. *lessonae* the tuber superior is very strong, produced laterally, is relatively steeper, and develops over the anterior border of the acetabulum. The West Runton fossils resemble *R*. *ridibunda* and *R*. "*esculenta*" in these characters. Today, *R*. "*esculenta*" is found in the adjacent low countries of the Continent (Arnold and Burton 1985, p.258, map 43), whereas *R*. *ridibunda* is found mainly in Spain and southwestern France (Arnold and Burton 1985, p.258, map 42). This is the first record of "water frog" from the Pleistocene of Britain. These species do not occur naturally in Britain today (Frazer 1983).

### *Rana temporaria* Linnaeus
(Figs. 1D and 2C)

*Previous Material* Material previously identified as *Rana temporaria* by Newton (1882a, b) has been assigned in the present paper to *Rana* sp. indet.

*New Material* John D. Clayden Collection: JCWR 13-15 from 168-172, two left and one right ilia; JCWR 16 from 173-177, sacral vertebra; JCWR 17 from 168-172, sacral vertebra. A.G. Savin

Collection BM(NH): R-6716, one left ilium; R-6720, four left and two right ilia R-10189, left ilium; R-6724, five sacral vertebrae and one sacral fused to presacral vertebra. A.G. Savin Collection NCM: 7.945 (119)B, sacral vertebra: 7.95(119)C, sacral vertebra. A.J. Stuart Collection UMZC: WR 305, right ilium from Sample A22; WR 393, right ilium from Sample A23; WR 747, right ilium from Sample A39; WR 1193, left ilium from Sample B17; WR 36, sacral vertebra from Sample A2; WR 93, sacral vertebra of juvenile from Sample A9.

This is a minimum number of 12 individuals based on 12 sacral vertebrae.

Remarks Böhme (1977) and Holman (1985) have discussed characters for distinguishing the ilia of *Rana temporaria* from other British and Continental species of *Rana*. The most important character in *R. temporaria* is the poorly developed vexillum (ilial blade). The sacral vertebrae of *R. temporaria* (Fig. 2) have the sacral diapophyses much more posteriorly directed than in other British and Continental species of *Rana*. *Rana temporaria* occurs in the area today (Frazer 1983).

### *Rana* sp. indet.

Previous Material Newton identified, with some doubt, both *Rana temporaria* (1882a, b) and *R. esculenta* (1882b) on the basis of humeri. These are now best considered *Rana* sp. indet. for reasons given below.

New Material John D. Clayden Collection: JCWR 18-39 from 168-172, 13 left and nine right ilia; JCWR 40-41 from 168-172, two sacral vertebrae; JCWR 42-48 from 173-177, seven sacral vertebrae; JCWR 49 from 168-172, left humerus. A.G. Savin Collection NCM: 7.745(113)A, left ilium; 7.945(113)B, radioulna. A.J. Stuart Collection UMZC: WR 1146, premaxillary fragment from Sample B14; WR 35, right ilium from

Sample A2; WR 916, right ilium from Sample B7; WR 1103, right ilium from Sample B12; WR 1194, left ilium fragment from Sample B17; WR 306, left humerus from Sample A22; WR 1308, left humerus from Sample B24; WR 1356, left humerus from Sample B25; WR 1801, left humerus from Sample C27.

This is a minimum number of 15 *Rana* sp. indet. based on 15 left ilia.

*Remarks* Newton's tentatively identified *Rana temporaria* and *R. esculenta* from the West Runton Freshwater Bed are here relegated to *Rana* sp. indet. Both of these identifications are based on humeri. Newton's (1882a, Pl.17, Fig. 7) is of a broken humerus, inadequate for the identification of *R. temporaria*. This specimen (BM(NH) R-2824) is presently in a state of decay. Newton's (1882b, p.9) "*Rana esculenta*?" recorded is based on a sexually dimorphic character that occurs in all male *Rana*, a ridge for the origin of the tendon going to the enlarged male thumb.

### Class Reptilia

### Order Squamata

### Family Anguidae

### *Anguis fragilis* Linnaeus

*Previous Material* None.

*New Material* A.G. Savin Collection BM(NH): R-6739, two vertebrae; R-10187, one vertebra.

This represents a minimum number of one individual.

*Remarks* These vertebrae are easily identified as Anguidae in lacking the zygosphene-zygantral articular processes of snakes and in lacking the ventral constriction of the centrum found in other British and European lizard families. The West Runton vertebrae appear identical to those in skeletons of modern Anguis fragilis. This species occurs in the area today (Frazer 1983).

### Family Colubridae

### Natrix natrix (Linnaeus)

Previous Material Newton (1882a, b) correctly identified Natrix natrix from the West Runton Freshwater Bed. His Figure 4, Plate 17 (1882a) illustrates a typical trunk vertebra of this species.

New Material A.G. Savin Collection BM(NH): R-2827, four vertebrae; R-6740, 10 vertebrae; R-6741, 19 vertebrae; R-6742, 20 vertebrae. A.J. Stuart Collection UMZC: WR 1862, a vertebra from Sample C30.

This is a rather large number of individual vertebrae, but they can be considered only to represent a minimum number of one individual.

Remarks Szyndlar (1984) and Holman (1985) have discussed the identification of this species on the basis of individual vertebrae.

### Family Viperidae

### Vipera berus (Linnaeus)

Previous Material This species is represented in the West Runton Freshwater Bed on the basis of a single vertebra (Newton, 1882 a, Plate 17, Fig. 6). The illustration indicates that the identification is correct (Holman, 1985, Szyndlar, 1984).

New Material None.

Remarks This species occurs in the area today (Frazer, 1983).

## DISCUSSION

All of the taxa of amphibians and reptiles thus far identified from the West Runton Freshwater Bed occur in East Anglia today (Frazer 1983) with the exception of two forms of Rana which presently occur on the European Continent. The moor frog Rana arvalis occurs from northeastern France eastwards; north to Sweden and Finland and south to the Alps, northern Yugoslavia and northern Rumania, as well as across Asia to Siberia (Arnold and Burton 1978, p.80 and map 37). The combined range of the edible or marsh frog Rana "esculenta" or ridibunda covers almost the entire European Continent including western Russia (Arnold and Burton p.85-87, map 42 and 43).

Stuart (1982) took the sedimentological and palaeontological evidence together and pictured the environment at the time of deposition of the West Runton Freshwater Bed. The scene was of a slow-flowing river, rich in aquatic plants and fringed by fen, such as is found in a typical English lowland river today. Herb-dominated habitats were present locally on the flood-plain interrupting the regional cover of temperate forest. The herpetofauna is perfectly consistent with this picture. The three forms of Rana, common toad Bufo Bufo, grass snake Natrix natrix and the newts Triturus spp. represent fen or waterside habitats, whereas the slow worm Anguis fragilis and adder Vipera berus inhabited the drier areas.

## ACKNOWLEDGEMENTS

We gratefully acknowledge Drs. T. Kemp and G. King of the University Museum, Oxford, for providing space for Holman's research in 1984 and 1986. Drs. J. Clack of the University Museum of Zoology, Cambridge, and A. Milner of the British Museum (Natural History) provided access to specimens in their care. The United States National Science Foundation (Grant BSR-8515665) provided funds for Holman's study in 1986. A Michigan State University Research Initiation Grant provided help for Holman's study in 1984. Lisa Hallock made the drawings.

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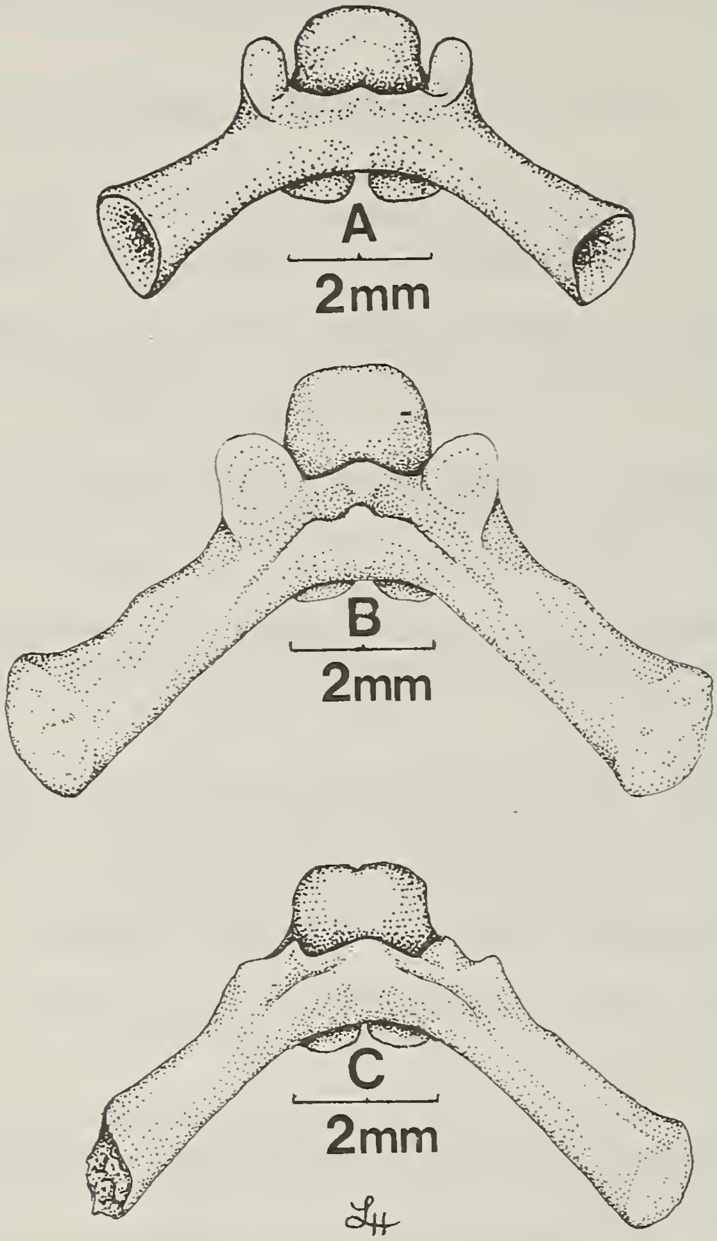

Figure 2. (A) Modern sacral vertebra of Rana "esculenta", Michigan State University No.3879. (B) Modern sacral vertebra of Rana temporaria, Michigan State University No.3867. (C) Fossil sacral vertebra of Rana temporaria, Norwich Castle Museum No.7.945(119)B

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The Geological Society of Norfolk exists to promote the study and knowledge of geology, particular in East Anglia, and holds monthly meetings throughout the year.

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Copies of the Bulletin may be obtained from the Secretary at the address given above; it is issued free to members.

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The illustration on the front cover is taken from Figure 286 of Lyell's "Elements of Geology", 1865 (6th Edition), and shows columns of potstones in the Late Campanian Chalk of a quarry on the River Bure near Horstead, Norfolk. The upper part of the section consists of Crag gravels resting on an erosion surface which truncates the potstone columns.

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BRITISH MUSEUM
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# BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

(FOR ARTICLES ON THE GEOLOGY OF EAST ANGLIA)

No.39 for 1989

CONTENTS INCLUDE:

Sedimentary Environments of the
North Norfolk Coast

Fossil Faunas of the Norwich Crag
of Bulcamp, Suffolk

BULLETIN of the GEOLOGICAL SOCIETY OF NORFOLK

No. 39 October 1990

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## EDITORIAL

We apologise for the considerable delay in publishing Bulletin No. 39, which was due in 1989. The paper by Pearson *et al.* was in fact actually set-up in 1989, and this should be borne in mind when reading it. In the event it has been overtaken by the publication elsewhere, of another paper, by Funnell and Pearson, describing the Holocene evolution of the North Norfolk coast in relation to sea-level change (see reference in Pearson *et al.* 1990). We hope readers will find Pearson *et al.* a comprehensive guide to sedimentary environments on the classic North Norfolk coast for some years to come.

The second half of Bulletin No. 39 is taken up by a series of specialist papers on the different faunal remains recovered from the Norwich Crag of Bulcamp, Suffolk, mainly as a result of the Society's excavations there in 1979. It proved an exceptionally rich site, and it has taken some time to gather together all the accounts of the different fossil groups which were obtained from there.

All being well 1990 will also see the publication of Bulletin No. 39A which will comprise a Reprint of Bulletin Numbers 11 to 18, and of Bulletin No. 40 for the year 1990 itself.

## Editorial

### INSTRUCTIONS TO AUTHORS

Potential contributors should note that although we prefer manuscripts to be submitted in typewritten copy we will accept neatly handwritten material. It is most helpful if the style of the paper, in terms of capitalisation, underlining, punctuation, etc. is made to conform strictly to those recently used in the Bulletin. All measurements should be given in metric units. The reference list is the author's responsibility and should always be carefully checked.

Illustrations are important. They should be drawn with thin dense black ink lines. Thick lines, close stipple or patches of solid black should be avoided as these tend to spread in the printing process usually employed. Original illustrations should, before, reproduction, be not more than 175 mm by 225 mm. Full use should be made of the first (horizontal) dimension, which corresponds to the width of print on the page, but the second (vertical) dimension is an upper limit only. Half-tone (photographic) plates can also be accepted, provided the originals exhibit adequate contrast, and when their use is warranted by the subject matter.

Authors are reminded that the Bulletin of the Geological Society of Norfolk exists to publish research papers, notes or general articles relevant to the geology of East Anglia as a whole, and does not restrict consideration to articles covering Norfolk alone.

Bull. geol. Soc. Norfolk, 39, 3-44 October 1990

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# SEDIMENTARY ENVIRONMENTS OF THE SANDY BARRIER/TIDAL MARSH COASTLINE OF NORTH NORFOLK

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## ABSTRACT

A map of the classic north Norfolk coast has been prepared from aerial photographs showing the spatial distribution of sediment and vegetation zones. Eleven geologically or botanically distinct environmental units are described in terms of sedimentological, vegetational and micro-faunal parameters. Twenty two of the twenty eight possible inter-unit comparisons are separable completely by at least one grain size parameter (mean grain size, sorting, skewness, percentage >4$\phi$), whilst separation of the remainder is possible over part of their grain size parameter ranges. Q-mode cluster analysis of benthonic foraminifera assemblages allow separation of the intertidal mud and marsh creek unit, the lower marsh unit and the four separate units recognised as mature salt marsh, from each other and from the dune unit and four sand or gravel based inter-tidal flat units. No separation was possible between the dune unit and inter-tidal flat sand units based on foraminifera assemblages.

The recognition of these units has provided a basis for the recognition of the depositional environments of sub-surface Holocene sediments in the area. In addition a further four environmental units present are described which are not recognisable as distinct units in sub-surface deposits. Using historical evidence the development and succession of the environmental units is outlined.

## INTRODUCTION

The North Norfolk tidal flats and coastal marshes (Fig. 1) are developed behind barrier islands, gravel ridges and spits, some with associated dune systems. These salt marshes, in varying stages of development are drained by major channels, often extending up to 3 km or so parallel to the coast before passing seaward across inter-tidal sand flats. The inter-tidal zone is up to 4 km in width. Tidal ranges vary from 2-3m at neap tides to 5-6m at spring tides (Admiralty Tide Tables, 1982) with peak spring tidal currents just offshore varying from 0.77m $s^{-1}$ in the west to 1.08m $s^{-1}$ in the east (Admiralty Chart No. 108).

There is a long history of research on the vegetation, topography and historical development of parts of the area. Steers (1960, 1969) has mapped coastal changes and produced localised data on sedimentology and coastal change. These, together with Chapman's (1960) work on the vegetational ecology, Pethick's (1971) thesis on salt marsh morphology, the investigation by Bayliss-Smith et al. (1979) into creek flows and McCave's (1978) paper on the inter-tidal sand sizes, have been significant contributions to knowledge of recent sedimentation in the area.

In this paper a map of lithofacies and vegetation zones is presented, with each environment being defined in terms of sedimentological, micro-faunal and vegetational parameters. By combining these parameters a method is arrived at for the recognition of modern depositional environments that can be applied directly to the interpretation of older Holocene sediments in the area.

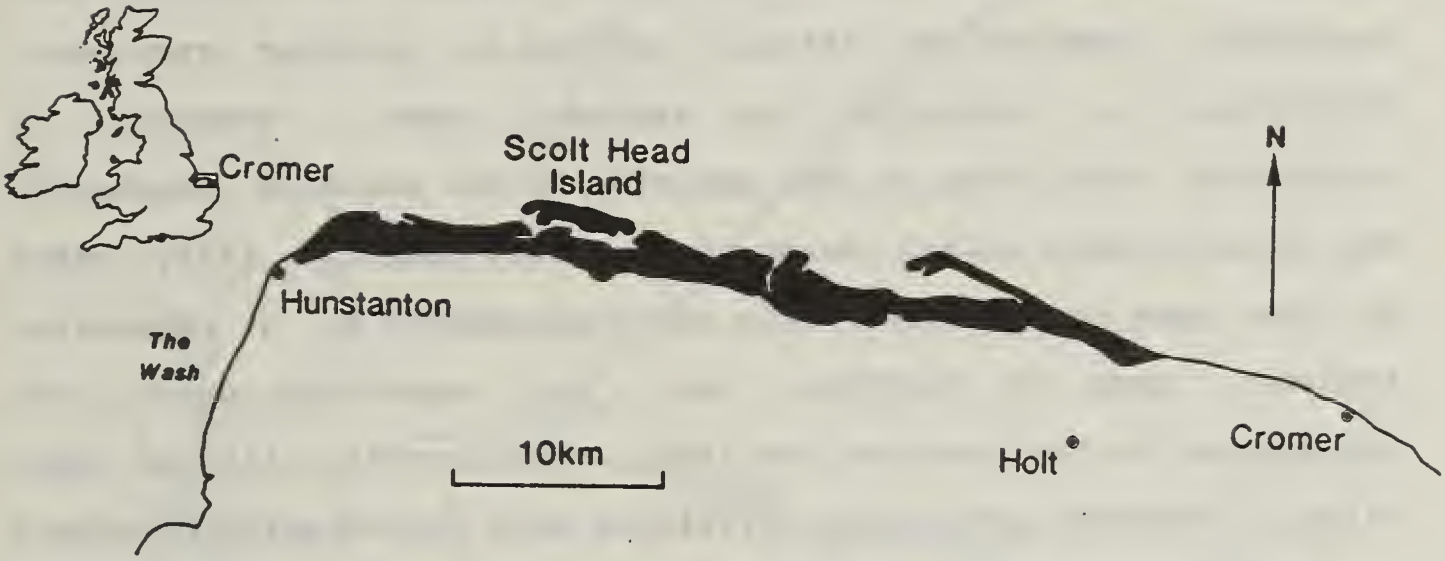


Figure 1 Location map of Norfolk, U.K. showing the study area

## METHODS

The spatial distribution of present-day environmental zones in the area has been investigated by the study of vertical panchromatic aerial photographs and by field sampling and mapping. Three sets of photographs taken in 1969 by Hunting Surveys Ltd. (HSL/UK/69/949 RUNS 2, 3 and 4) at a scale of 1:10,560 provided the source from which data was extracted using a grid overlay on stereoscopic pairs. This was supplemented by ground truth surveys. Unfortunately neither colour, nor false colour, photographs were available, creating an initial problem in relating grey-scale differences to vegetation and sediment types. However, in initiating this study we were assisted by the existing vegetation map of Scolt Head Island (Nature Conservancy Council, 1973), based on the same photographs. This was supplemented by a vegetation transect made at Stiffkey and, for vegetation types not represented in the previous two areas, field verification at other sites. Sediment grey-scale variations were investigated by ground truth surveys of distributions in the Stiffkey, Blakeney, Wells and Holkham Gap areas.

The greatest problem in delineating the sedimentary and vegetational divisions was ensuring that each was distinct enough to be distinguishable, both by aerial photography and by measured parameters.

To help in this recognition several standard sedimentological determinations and examination of the foraminifera species assemblages have been used. Samples were first collected along a transect at Stiffkey (Fig. 2) with additional samples collected at Holkham Gap, Wells and Brancaster respectively. Along the transect sampling points were separated by 10m across the upper salt marsh, 20m in the inter-tidal zone and 35m along salt marsh creek beds.

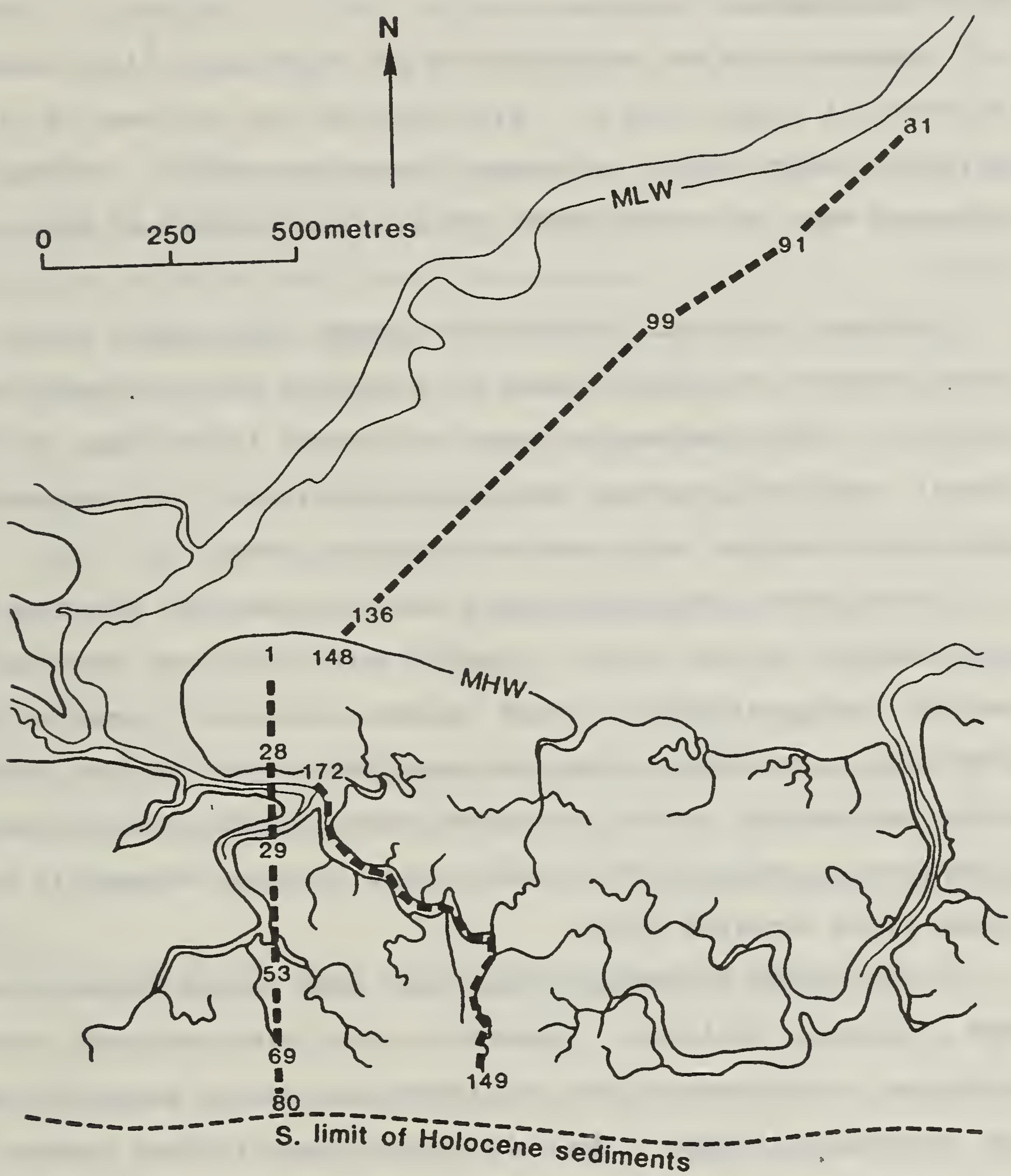


Figure 2 Location of sediment sample transect at Stiffkey with sample numbers shown.

At each sample point the upper 5 cm of sediment was taken for analysis. Sedimentological analyses were carried out over the whole depth of each sample, no attempt being made to look at differences between laminae.

Sediment size was determined by wet sieving at $^1/_2\phi$ intervals for material larger than $4\phi$. Fine material was analysed by pipette analysis. Statistical parameters (mean grain size, sorting and skewness) were calculated using the graphical method of Folk & Ward (1957).

Samples from all environments except dunes were tested for organic carbon and $CaCO_3$ content, calculated by percentage loss on ignition. Dune sediments were not tested in this way as both organic and $CaCO_3$ content vary considerably with the vegetational and decalcification stage reached (Chapman, 1960).

Foraminifera assemblages were examined from the 125µm to 500µm size fraction of each sample. Smaller size fractions were excluded due to the possibility of high concentrations of juvenile tests producing anomalous assemblage proportions for certain species. Scott and Medioli (1978) have shown that assemblage variations of foraminifera can be used to trace small vertical changes in marsh height along transect lines.

In this study assemblage variations have been compared using Q-mode cluster analysis. Numerical data were analysed using a technique equivalent to the unweighted pair-group method of Sokal and Michener (1958). This is the average linkage method and similarity ratio no.28 from the CLUSTAN analysis package (Wishart, 1978). The comparison of sub-surface sample assemblages with predefined clusters from surface samples is of great value in determining depositional environment where vertical sampling is not continuous.

## RESULTS

### 1. The Sedimentary Environments

The aerial photographic interpretation and ground truth surveys resulted in the definition of 6 sedimentary and 8 vegetational units with 1 unit falling into both categories (Table 1).

The 6 sediment units (numbered (i) to (vi) below) were well separated by their grey scale differences or by topographic variations visible from stereo photographs.

(i) Inter-tidal Gravel was readily identifiable where it occurred in large patches, for example north of Stiffkey, but proved impossible to define consistently on beach bars where it occurs patchily. Therefore the latter are shown as sand.

Sand and mud deposits characterise the high and low energy environments respectively. (ii) Inter-tidal Sand occurs over large expanses of open tidal flat although in some of the larger creeks a higher gravel content defines (iii) Channel Sand. Areas of exceptionally low gradient, generally not completely drained at low tide, or areas sheltered behind high beach bars show development of thin flasers or mud drapes and form (iv) Inter-tidal Silty-Sand unit.

Muddy deposits are laid down in areas sheltered from waves behind barriers or spits, immediately in front of barriers or spits where they are protected by high beach bar development to seaward, or within salt marsh creek systems. These areas have been amalgamated into (v) an Inter-tidal Mud and Marsh Creek unit.

Small areas of (vi) Older Holocene sediments deposited at a lower level during the Flandrian transgression and now exposed on the foreshore by erosion and coastal retreat form the sixth sedimentary unit.

| Differentiated unit | | Differentiated from | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sediment | Vegetation | Channel Sand | I/T Gravel | I/T Sandy Silt | I/T Sand | I/T Mud and Marsh Creek | Dune | Lower Marsh | Upper Marsh |
| Channel Sand | | – | G | G | g | GF | | GF | GF |
| I/T Gravel | | G | – | G | G | GF | G | GF | GF |
| I/T Silty Sand | | G | G | – | G | gF | G | GF | GF |
| I/T Sand | | g | G | G | – | GF | g | GF | GF |
| I/T Mud and Marsh Creek | | GF | GF | gF | GF | – | GF | | GF |
| Dune | Dune | g | G | G | | GF | – | GF | GF |
| | Lower Marsh | GF | GF | GF | GF | gF | GF | – | F |
| | Upper Marsh | GF | GF | GF | GF | GF | GF | gF | – |
| | Suaeda fruticosa | | | | | | | | |
| | Phragmites | | | | | | | | |
| | Grass | | | | | | | | |

Table 1 The separation of environmental units by sediment and microfaunal parameters.

G = separable completely by at least one grain size parameter

g = separable over part of their ranges by at least one grain size parameter

F = separable by foraminifera assemblage composition

## 2. The Vegetation Units

Of the 8 defined vegetation units (i to viii below) the largest area is represented by the 4 units that occupy the higher salt marsh areas.

The species composition of vegetation across a salt marsh varies with the height of the marsh surface relative to sea level. This is in response to the period of salt water submergence that each species can tolerate (Chapman, 1960). Although vegetational succession is progressive, a distinction between Upper and Lower Marsh communities gives a guide to relative marsh surface height and developmental stage. This division has been based on the first visible occurrence of Halimione portulacoides (sea purslane), a species that is easily identifiable from aerial photographs due to its pale foliage, occurring at a minimum level of + 2.05m O.D. (Chapman, 1960). However, this level does not appear to be consistent, being up to 0.4m higher on the more open, mature, areas of marsh.

Plotted separately from (i) the Upper Marsh unit are (ii) Phragmites reed beds, occurring in brackish water environments at the landward edge of some marshes or at the edges of river channels. Another marker species which delineates the upper limit of the salt marsh, (iii) Suaeda fruticosa (shrubby sea-blite) has also been plotted separately. In addition to the marsh edge this species also occurs on the slightly higher, sandier, better drained areas along creek levees (where, unless it forms a particularly large or dense area, it has not been shown) and more importantly, at the dividing line between marsh and dune vegetation. It is in this latter situation that together with areas of (iv) salt marsh grasses, the species reflect sediment variations providing, where

(text continues on p. 24)

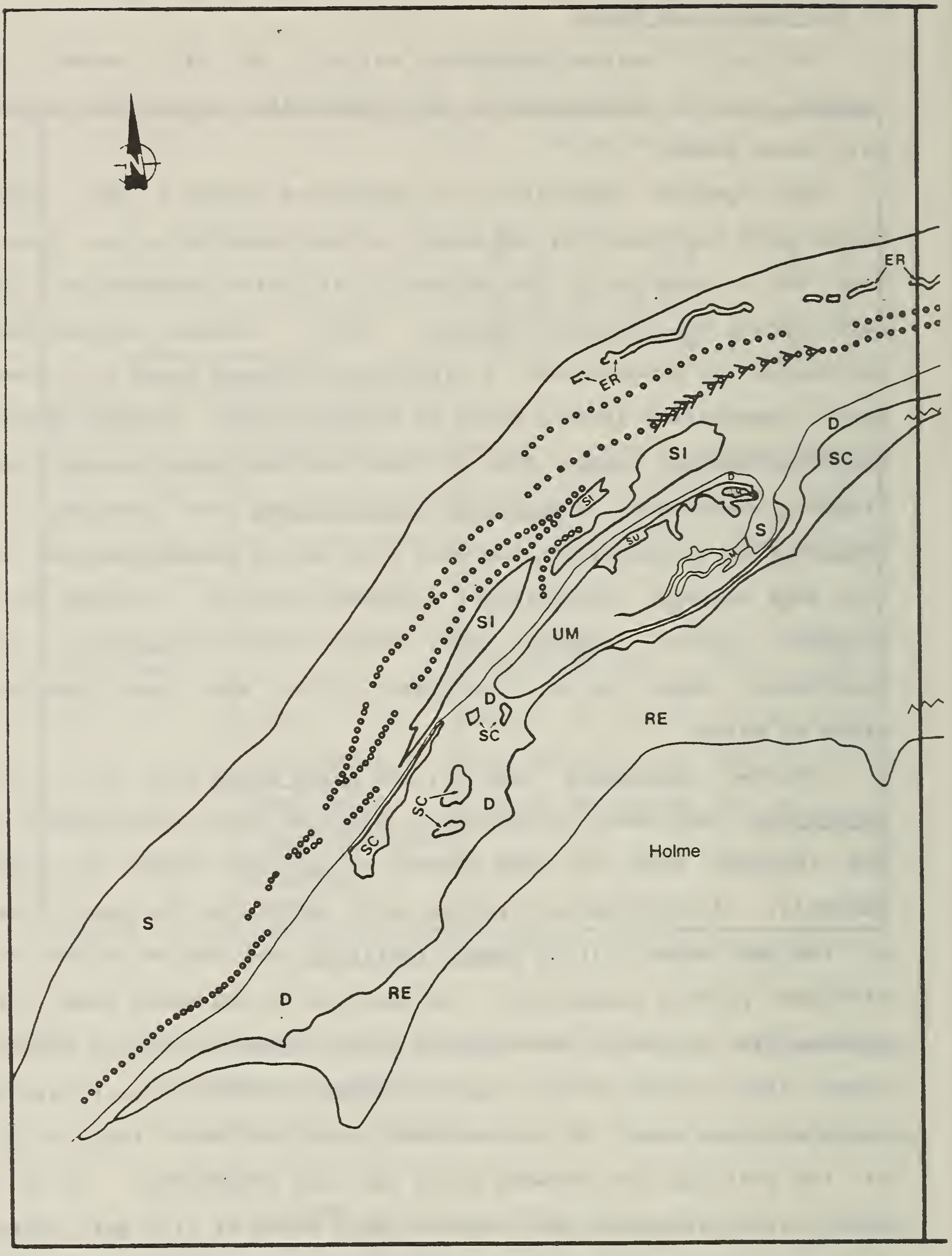
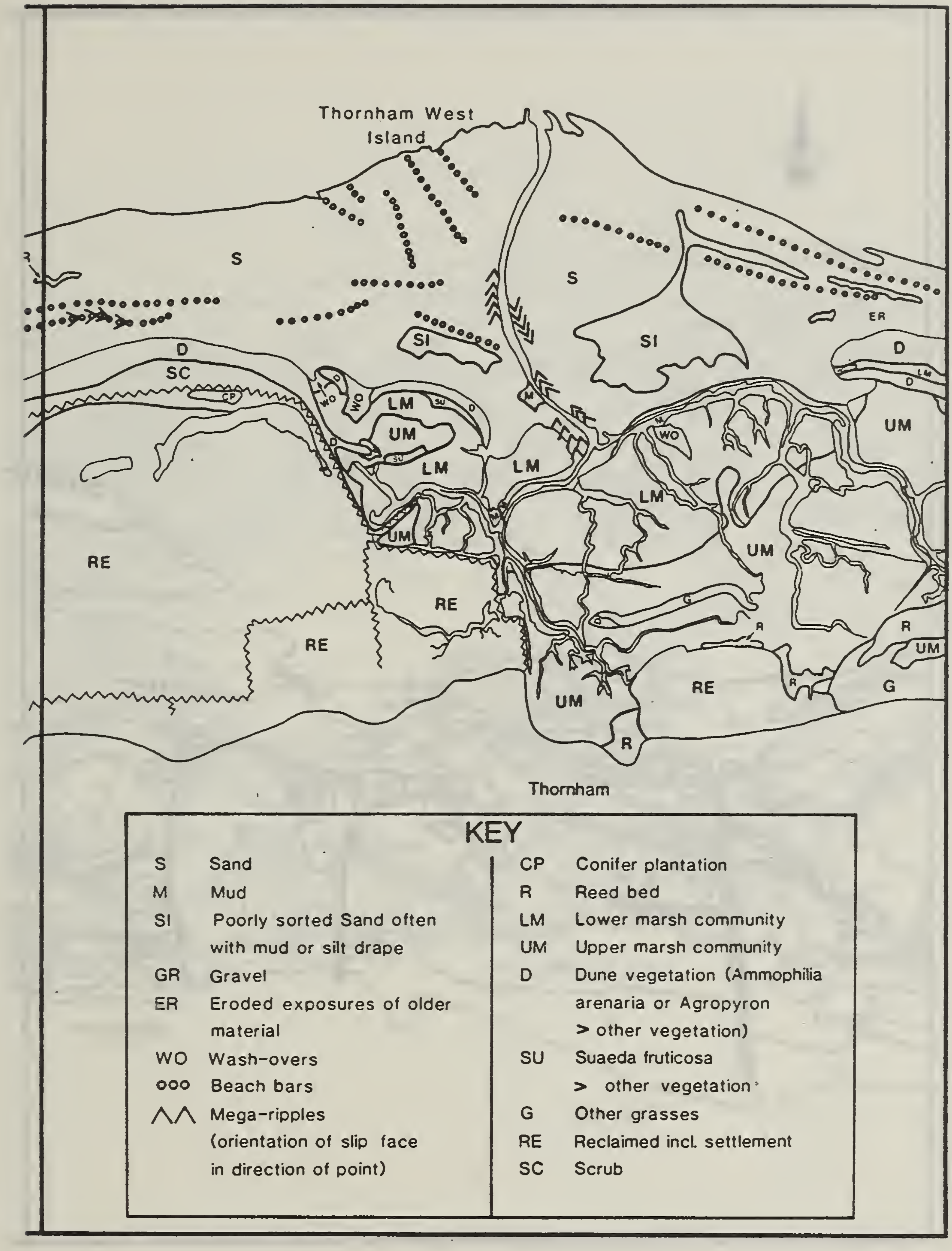


Figure 3a Distribution of environmental units along the North Norfolk coast in 1969 ....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S Sand
M Mud
SI Poorly sorted Sand often with mud or silt drape
GR Gravel
ER Eroded exposures of older material
WO Wash-overs
ooo Beach bars
⋀⋀ Mega-ripples (orientation of slip face in direction of point)
CP Conifer plantation
R Reed bed
LM Lower marsh community
UM Upper marsh community
D Dune vegetation (Ammophilia arenaria or Agropyron > other vegetation)
SU Suaeda fruticosa > other vegetation
G Other grasses
RE Reclaimed incl. settlement
SC Scrub

Figure 3b

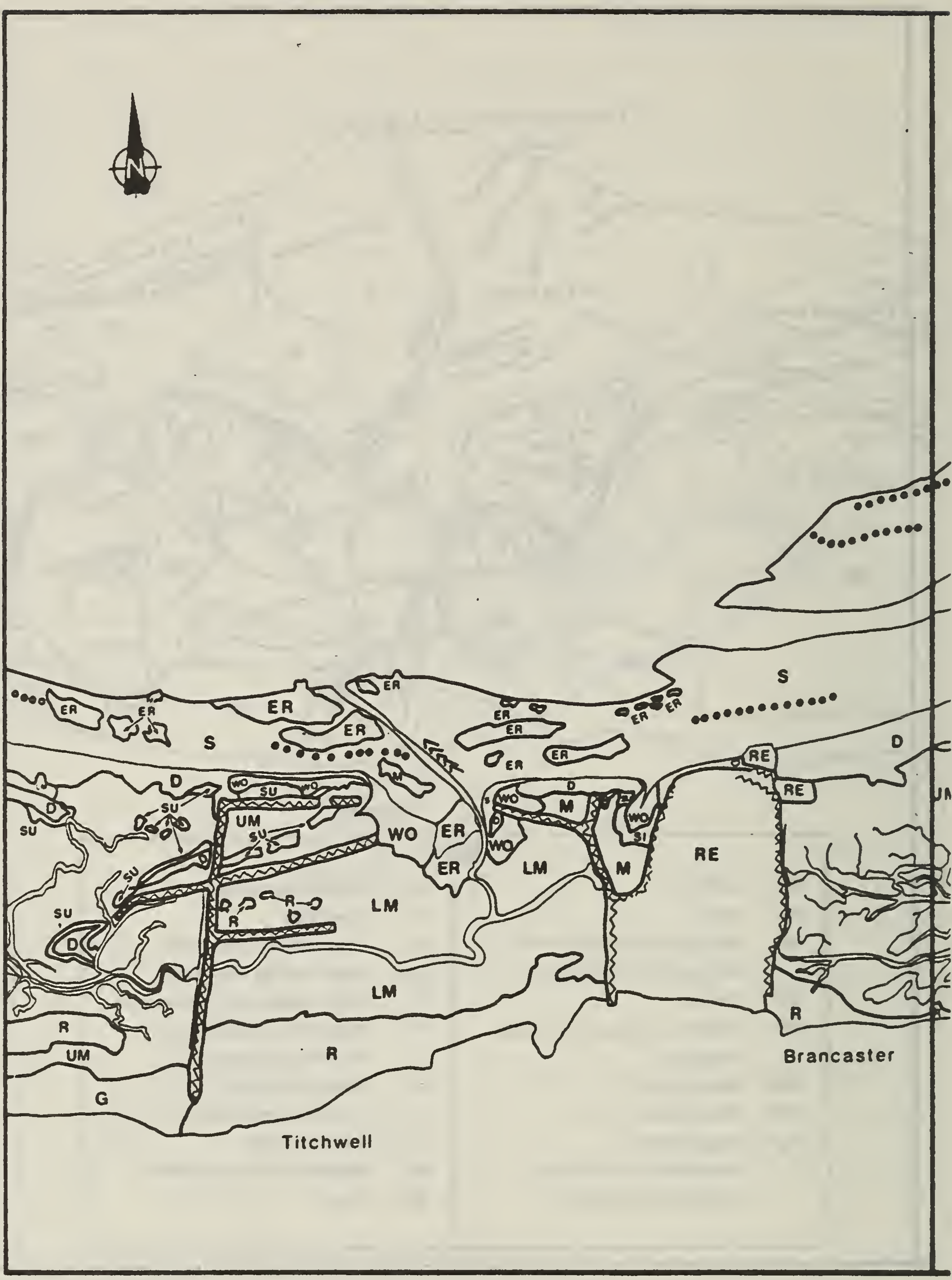
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Figure 3c

Tidal environments of North Norfolk

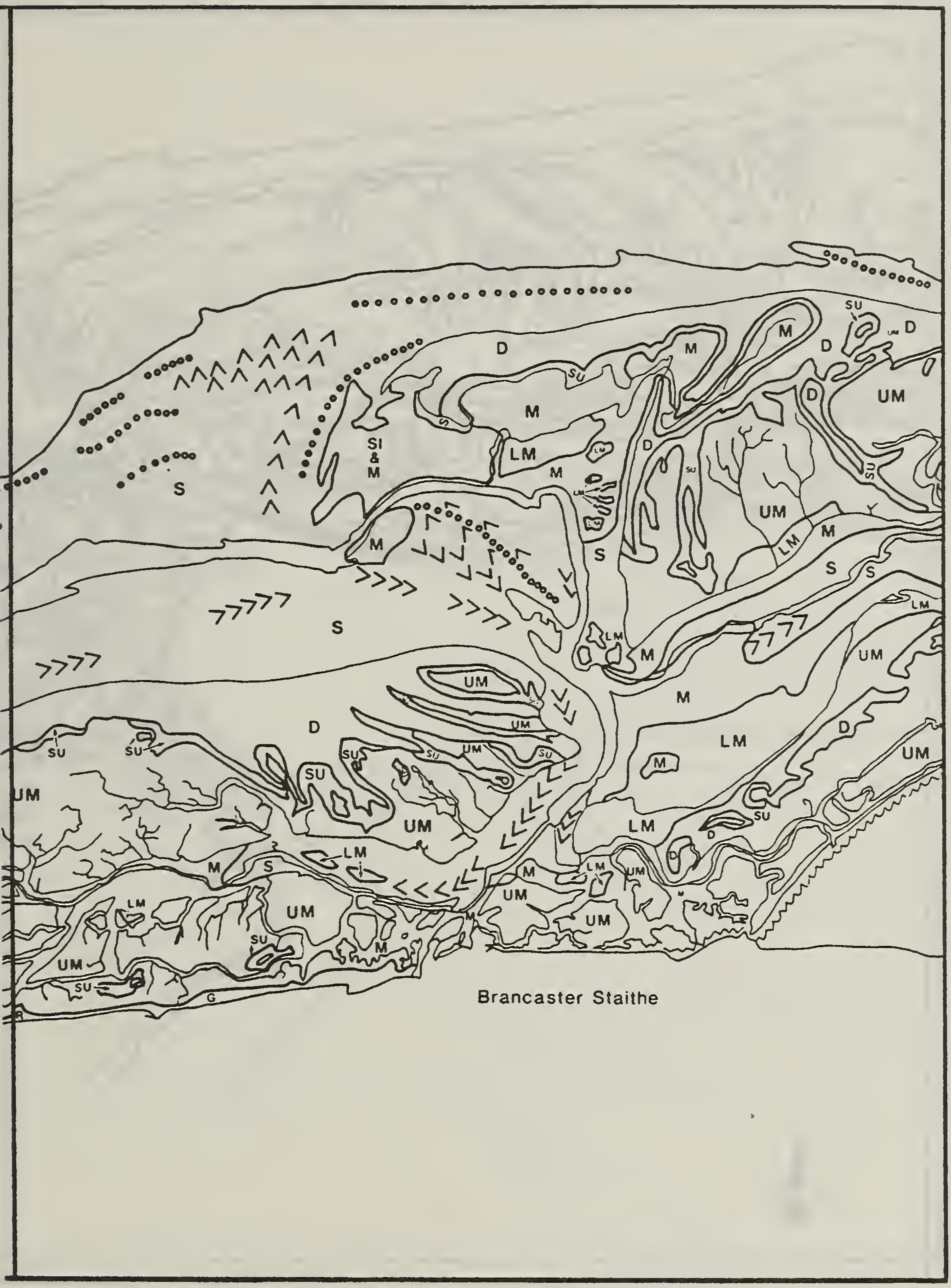
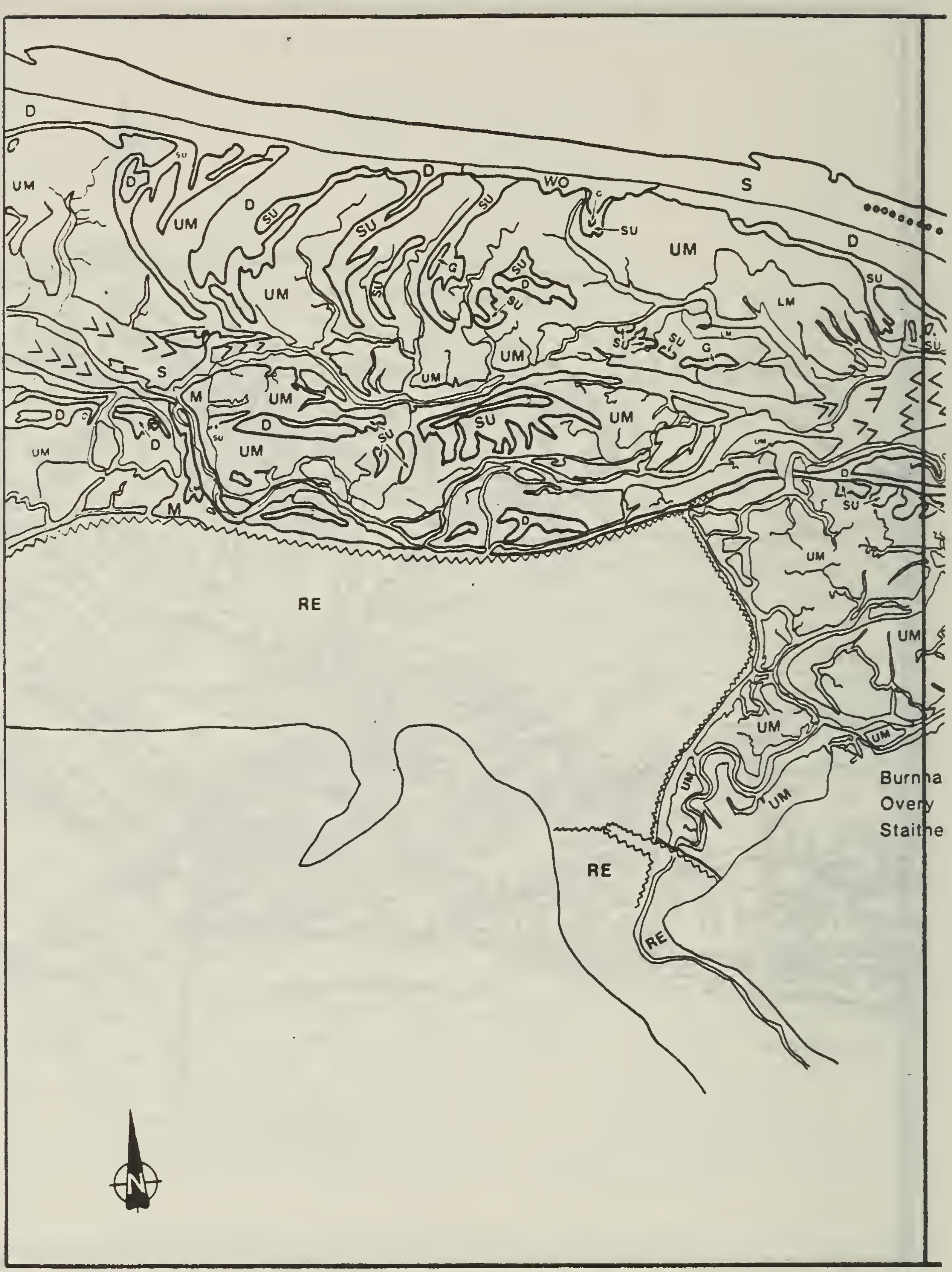


Figure 3d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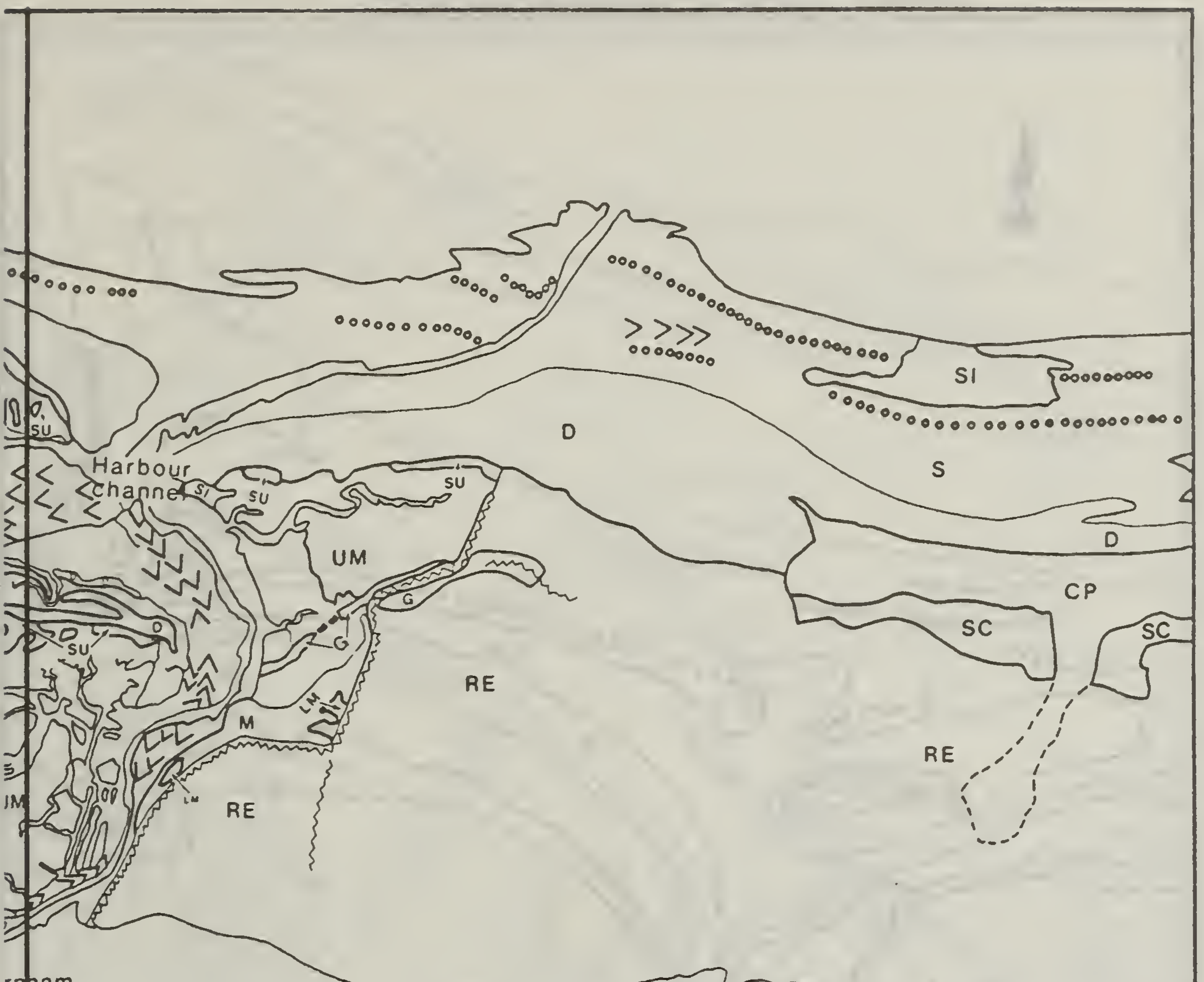
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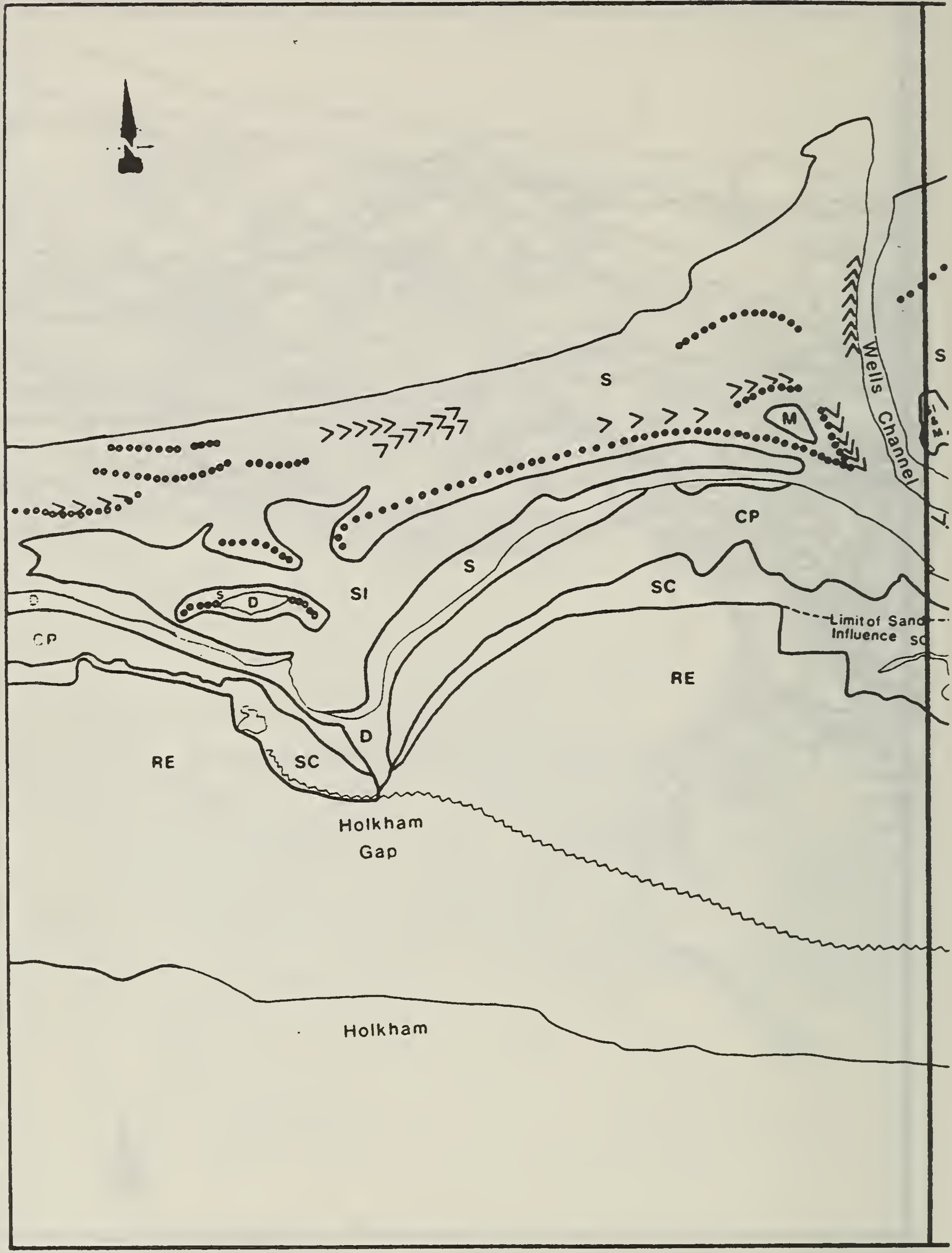
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Figure 3g

Tidal environments of North Norfolk

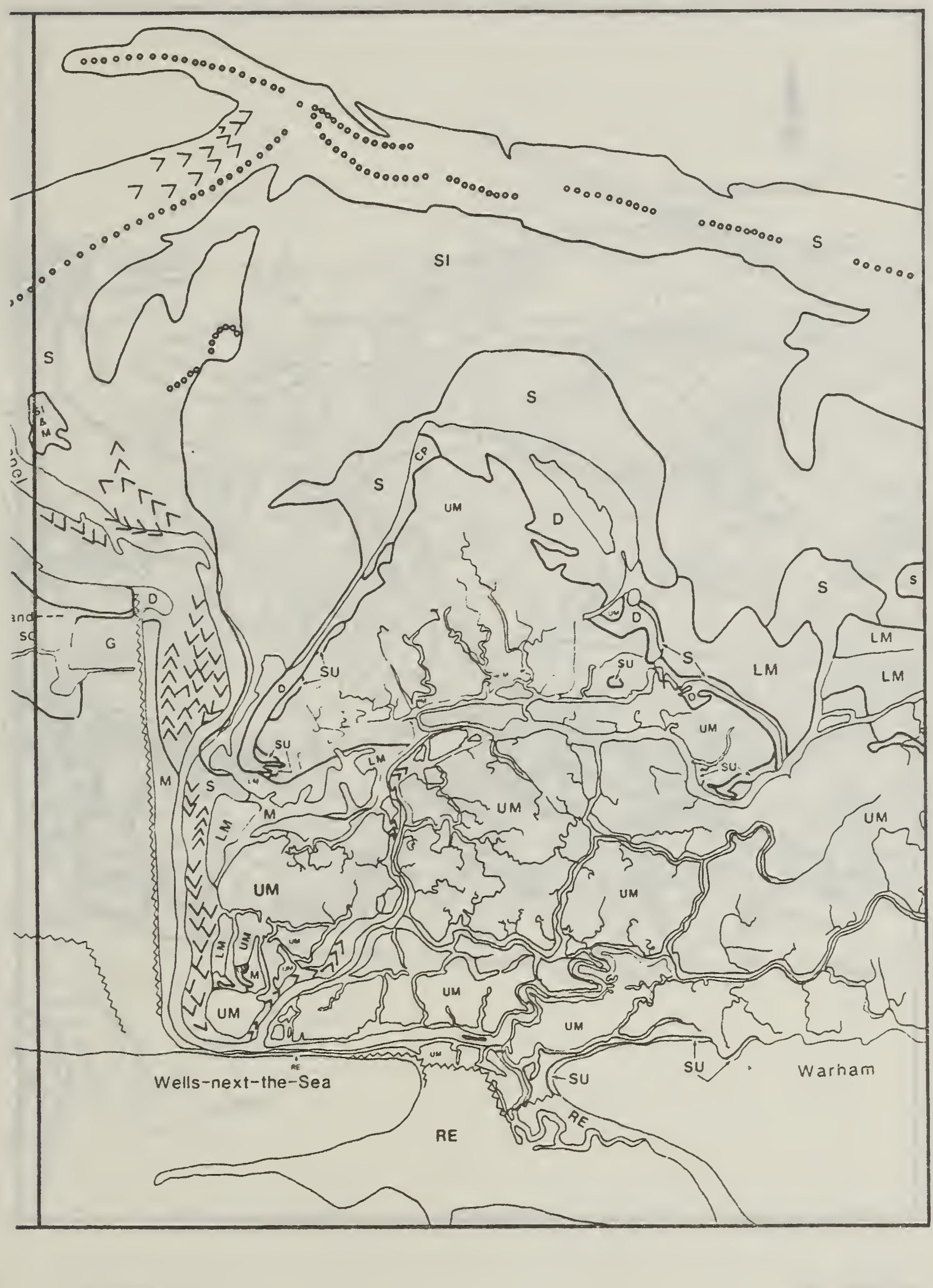

Figure 3h

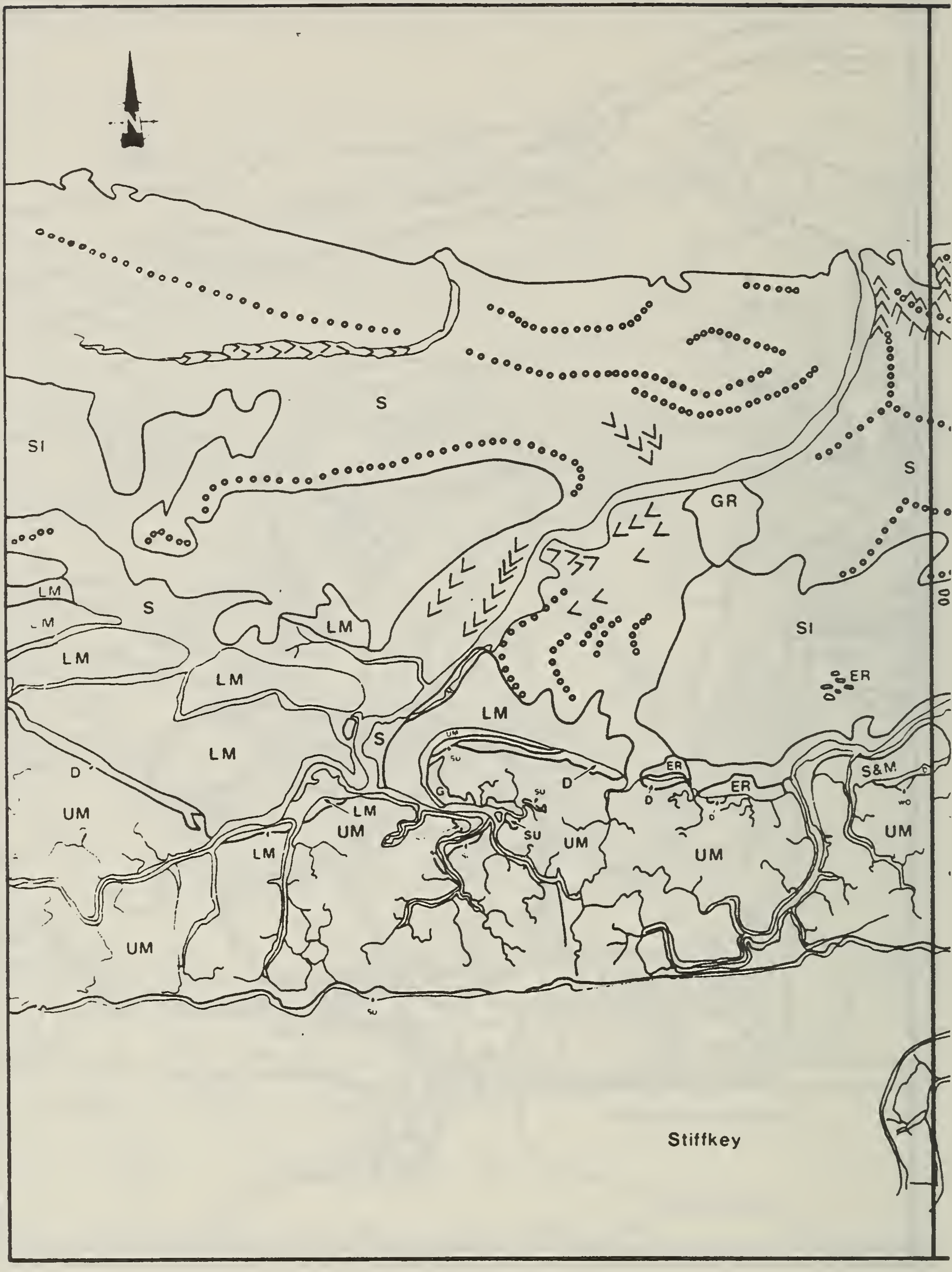
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Figure 3i

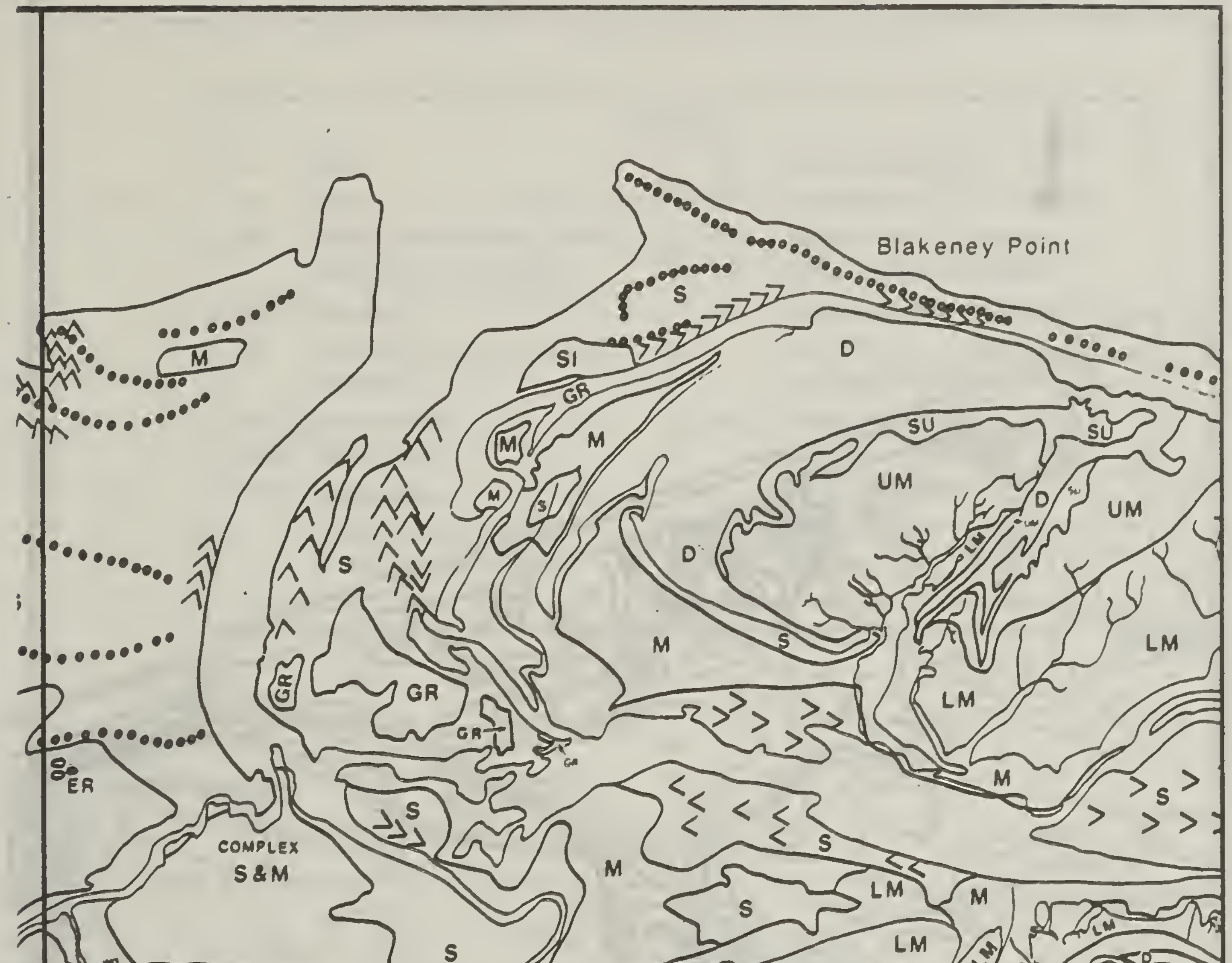
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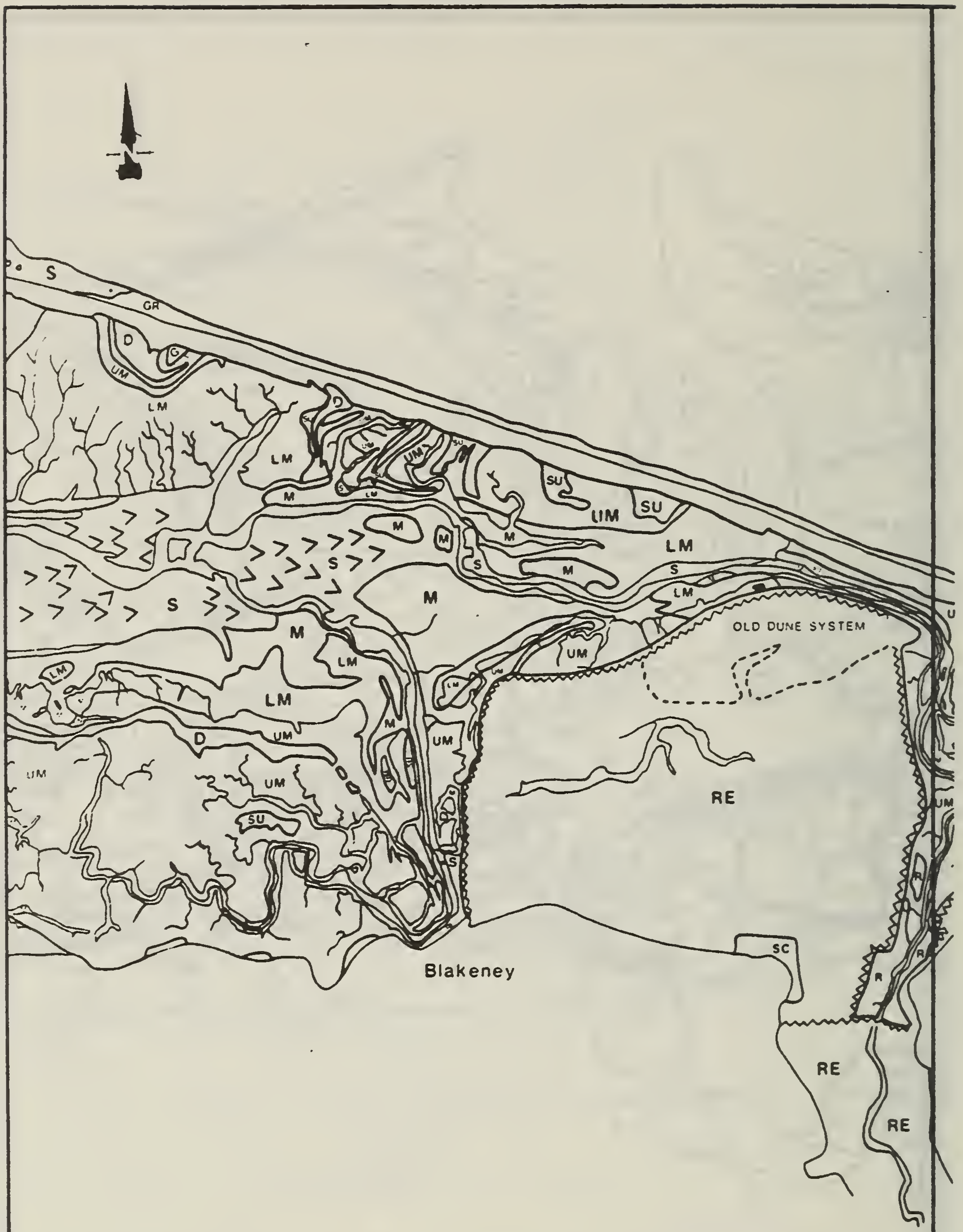
Figure 3j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OLD DUNE SYSTEM
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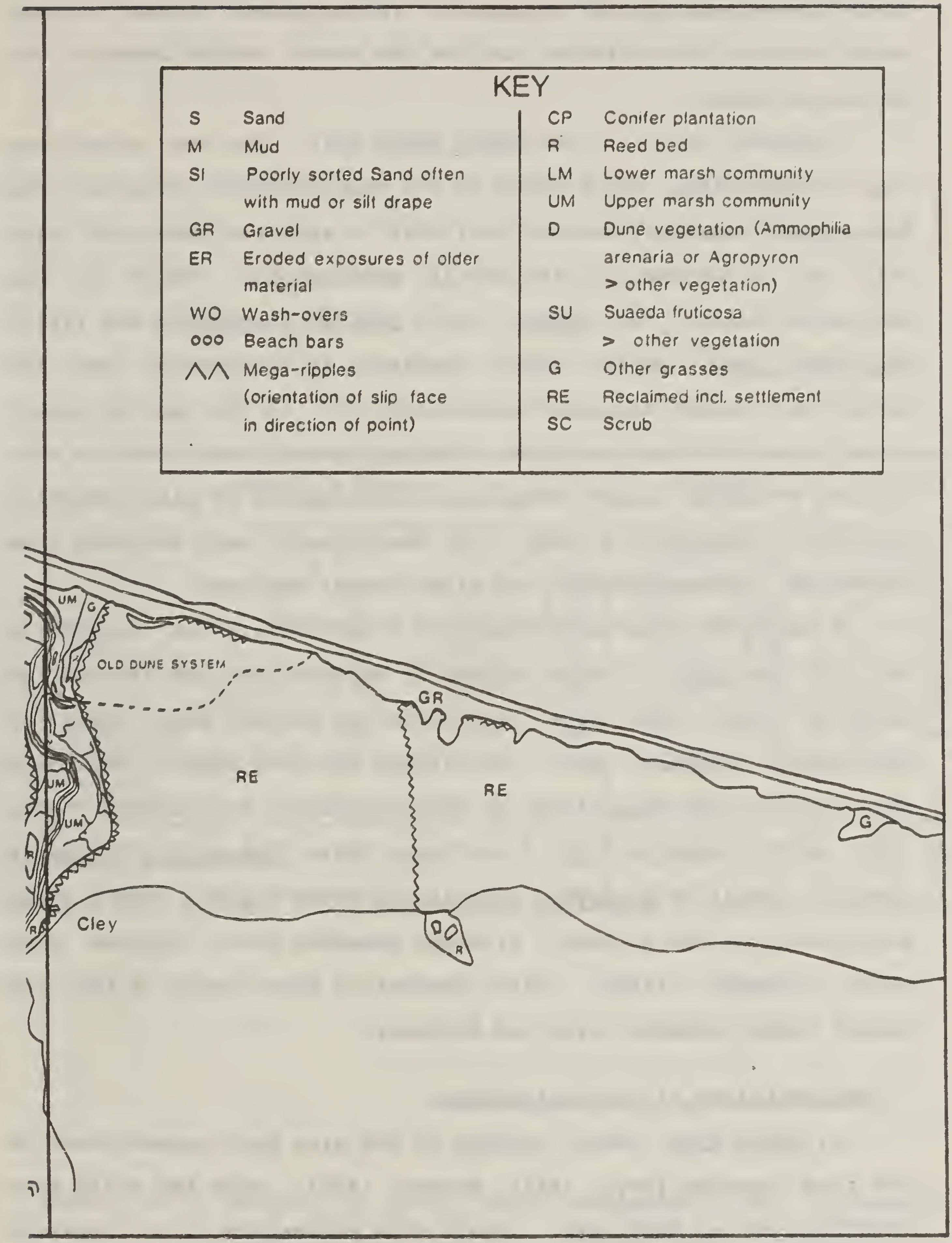
Figure 3k


KEY
S Sand
M Mud
Sl Poorly sorted Sand often with mud or silt drape
GR Gravel
ER Eroded exposures of older material
WO Wash-overs
ooo Beach bars
⋀⋀ Mega-ripples (orientation of slip face in direction of point)
CP Conifer plantation
R Reed bed
LM Lower marsh community
UM Upper marsh community
D Dune vegetation (Ammophilia arenaria or Agropyron > other vegetation)
SU Suaeda fruticosa > other vegetation
G Other grasses
RE Reclaimed incl. settlement
SC Scrub
UM
G
OLD DUNE SYSTEM
GR
RE
RE
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Cley
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Figure 31

there are no dune plants, evidence of relict gravel ridges, barrier sands and spit recurvatures that are now almost buried beneath the developing marsh.

Included in (v), the Lower Marsh unit, are the colonising algal communities, which occur at the same relative levels as the *Zosteretum* community and are difficult to separate from each other with any consistency on the aerial photographs. Three of the vegetation units, (vi) Scrub, (vii) Conifer Plantation and (viii) Reclaimed Land, whilst being important at the present day are either very recent man-made environments or, in the case of Scrub, occur in an area that would be indistinguishable from Dunes in sub-surface sediments unless exceptional preservation of plant material occurred. Consequently these three environments were excluded from subsequent sedimentological and micro-faunal analyses.

A composite area identifiable as a sedimentary and vegetation unit are the dunes. Large patches of exposed sand are visible as washover fans, wind blow outs or in the yellow dune stage of development (Chapman, 1960). No attempt has been made to delineate the various dune communities or stages in dune development. The dune units shown in Fig. 3 are areas where *Ammophilia arenaria* (marram grass) or *Agropyron junceiforme* (sand twitch) form a large proportion of the foliage, although numerous other species also occur (Chapman, 1960). This vegetation also occurs on the low gravel ridges between Wells and Blakeney.

## 3. Sedimentology of the Environments

a) grain size. Past studies in the area have concentrated on the sand fraction (Roy, 1967; McCave, 1978). Here the whole size distribution has been used. Grain size parameters do not separate all the depositional environments of the area, but do help to

| | Mean Grain Size (ø) | $\sigma_I$ (ø) | Skewness | % >4ø |
|---|---|---|---|---|
| Channel Sand | 1.43 to 2.19 | 0.44 to 0.74 | -0.18 to 0.02 | 95 to 96 |
| I/T Gravel | 0.45 1.07 | 1.32 2.16 | -0.3 -0.03 | 96 100 |
| I/T Sand | 1.82 2.26 | 0.05 0.76 | -0.31 0.25 | 94 100 |
| Dune | 1.83 2.25 | 0.28 0.52 | -0.14 0.05 | 95 100 |
| I/T Silty Sand | 3.49 4.17 | 1.98 2.94 | 0.75 0.81 | 67 78 |
| I/T Mud and Marsh Creek | 3.8 5.39 | 2.31 3.14 | 0.47 0.75 | 24 68 |
| Lower Marsh | 4.66 5.79 | 2.1 3.13 | 0.34 0.68 | 28 58 |
| Upper Marsh | 5.49 6.99 | 2.32 3.09 | 0.18 0.73 | 6 33 |

Table 2 Ranges of grain size parameters for different environmental units. (Upper Marsh includes all associated units in Table 1)

differentiate the extremes. All grain size parameters are shown as a range of values rather than the mean of the respective sample means. This is of more use in environmental differentiation as it shows more clearly areas of overlap between units.

Areas where the sediment type is composed almost entirely of sand, (Dune, Inter-tidal Sand and Channel Sand), are not separable using any of the grain size parameters calculated (Table 2). All three ranges for mean grain size ($M_z$) overlap, although channel sand has the coarsest range from 2.19$\phi$ to 1.43$\phi$. Inter-tidal sand is slightly finer at the lower end of its range, but nearly $^1/_2\phi$ finer at the coarse end, a high proportion of the larger grain size material being preferentially transported to either the back beach or beach bar crests. There were no back beach deposits in the areas sampled for this study.

Dune sands have a smaller range for $M_z$ and $_I$ than inter-tidal sand although all of the samples fall within the $M_z$ range for inter-tidal sand. This supports the view of Roy (1967) and Steers (1960) that dune material on this coast is derived from the inter-tidal flat environments. Inter-tidal gravels are separable from both dune and inter-tidal sands using mean grain size. Sorting values vary from very well sorted to moderately sorted (Folk and Ward, 1957), with dune sand having the most consistent sorting. Skewness values are close to zero for all four of the previously mentioned environmental units. The grain size parameter values for Dune and Inter-tidal Sand support the work of Shepard and Young (1961) who, unlike Mason and Folk (1958), found that these two environments could not be separated using this parameter.

The remaining environmental units form a continuum in their mean grain size ranges and sand and gravel percentages, all of them being separable from the above mentioned sand environments by these parameters. Upper Marsh (including Suaeda fruticosa, grass and Phragmites) and Inter-tidal Silty Sand areas are easily separable by mean size having at least 1.32ø between their two ranges, and although sorting values are similar the Inter-tidal Silty Sand sediments are more positively skewed. Upper Marsh deposits are also separable from Marsh Creek and Inter-tidal Muds by their grain sizes although other parameters overlap. Lower Marsh and Inter-tidal Muds are inseparable although the Inter-tidal Muds are very slightly coarser over part of their $M_Z$ range. A slight overlap in mean grain sizes occurs between Upper Marsh and Lower Marsh sediments although over most of their size ranges they are separable by this parameter.

An analysis of the sediments from all the environmental units into size classes illustrates the existence of two major modal grain sizes on the North Norfolk coast. The largest mode consists of the size classes between 1.5ø and 2.5ø and forms the major portion of all the sand based environments. This mode is however also a prominent component of the marginal, muddy, higher inter-tidal units, (Marsh Creeks, Inter-tidal Mud and Lower Marsh), where it is transported from the large sandflat areas.

Roy (1967) who used a settling tube, also found a sand fraction mode between 1.7ø and 2.4ø which he divided into two parts. He compared his modal distributions with that of boulder clay outcropping near Scolt Head Island and concluded that the sand component originated from this source, although it is more probable that their immediate origin is from fluvio-glacial outwash exposures.

The other major modal component occurs mainly in the finer grained sediment types of Upper and Lower Marsh, Marsh Creek and Inter-tidal Mud, and also occurs in Inter-tidal Silty Sand samples.

The peak occurs in the classes between 4.5$\phi$ and 5.5$\phi$. The origin of this material is speculative but could represent the reworked silt size component of glacial material as less than 5% appears to be of local biogenic origin.

b) organic matter and $CaCO_3$ variation. Several authors have noted that higher calcium carbonate content occurs in finer grained sediments (van Straaten, 1954; van Andel and Postma, 1954; Evans, 1960; Battacharyya, 1967; Roy, 1967) a trend also found in this study. However, the $CaCO_3$ content in the Upper Marsh, Lower Marsh and Marsh Creek areas varies from 0.08% to 8.32% $CaCO_3$. Inter-tidal flat areas (Inter-tidal Sand, Silty Sand and Gravel) have a smaller range from 0.26% to 1.36%. The main source of carbonate is thought to be the skeletal remains of inter-tidal organisms including foraminifera, which, in a degraded state, are transported to the lower energy environments, together with carbonate derived from adjacent chalk areas (Roy, 1967).

Organic matter content follows the same pattern as $CaCO_3$ content, being higher in the finer grained environments where it is incorporated directly into the sediments from local vegetation.

Although a clear distinction exists between Inter-tidal and Upper Marsh areas the data on both organic and carbonate content reveal little more than could already be ascertained from the grain size analyses.

c) bedforms. Two major types of bedform were visible on the aerial photographs. These are shown in Figure 3 as megaripple fields and beach bars.

Beach bars vary in height from 0.5m to 2m. In the majority of cases the orientation is sub-parallel to the coast. More mature bars often possess a characteristic recurvature at either end.

Megaripple fields can be divided into two groups. Those that occur in the region of large drainage channels where a real asymmetry of tidal flow is demonstrated, as in the study area of Allen and Friend (1976) in the Wells Channel, and those that occur on the open sandflats where the megaripple orientations reflect the strongest current direction, attained 2 hours before high water when the flood tide is flowing from west to east.

## 4. Foraminifera

The analysis of foraminifers has shown four distinct assemblages (Fig. 4).

Samples taken from the Upper Marsh (including areas of *Suaeda fruticosa*, and *Phragmites* reeds) are distinguished from the other three divisions by the high percentage of two Textularine species, *Jadammina macrescens* and *Trochammina inflata*. Both of these species can withstand the extreme environmental variability encountered in the high marsh areas. *Phragmites* reed beds fall within the limits of this group due to the high number of *J. macrescens* in this environment.

The Lower Marsh assemblage contains relatively few Textularine Foraminifera. The lower level and frequent inundation by the sea allows more marine species to inhabit this unit with the most hyposaline tolerant species of *Elphidium*, *E. williamsoni* being the delineating species for this group.

Marsh Creek and Intertidal Mud units fall within the same cluster group. These areas have an assemblage intermediate between those of the Upper Marsh and the Inter-tidal Sand areas. Two main species occur in varying proportions, *Protelphidium germanicum*, (an estuarine-type species which can tolerate low salinity conditions), and *Nonion depressulus*, (a more marine species), with the remainder

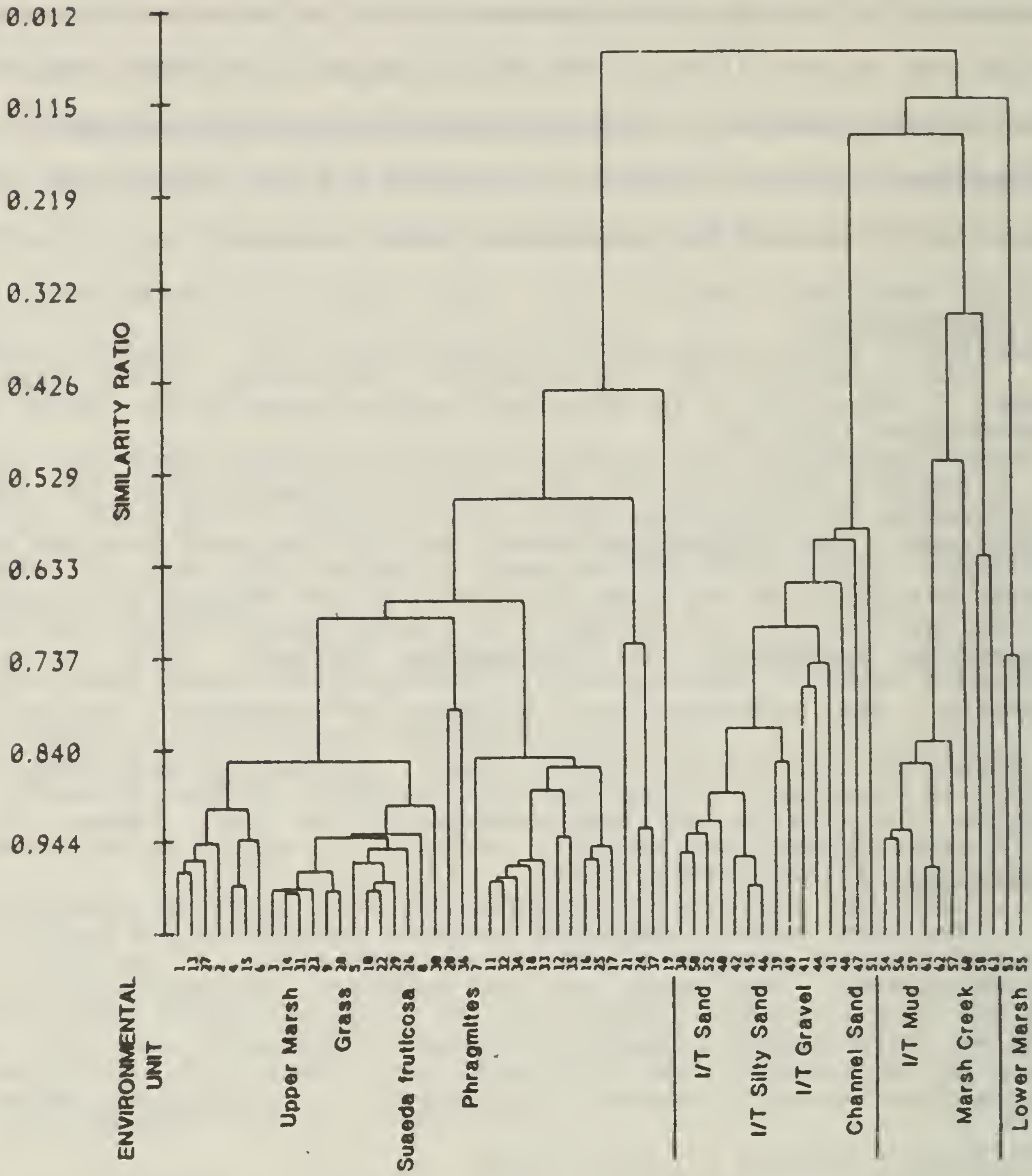

Figure 4 Q mode cluster analysis (unweighted pair-group method) of benthonic foraminiferal assemblages showing their environmental units. (For clarity, a representative selection of samples is shown. Numbers refer to computer input criteria, not sample numbers.)

of the assemblage consisting of small quantities of the main upper and lower marsh species, some possibly derived from creek banks, and the main inter-tidal sand flat species, _Ammonia_ _beccarii_ _batavus_. Three varieties of the species _A_. _beccarii_ occur within the area. Two, '_limnetes_' and '_tepida_', are brackish water varieties and confined to the upper marsh and creeks. The third, '_batavus_', is the main species in inter-tidal sand, silty sand and gravel units where other species include _N_. _depressulus_ and small numbers of _P_. _germanicum_ and some of the more marine species of _Elphidium_. The derivation of dune sands from the inter-tidal area is supported by the foraminiferal assemblages, where samples from both environmental units fall within the same cluster group.

## 5. Distribution and Morphology

The present-day environments recognised in this study are distributed sub-parallel to the northern edge of the pre-Holocene sediments. The zonation can be divided into three main areas.

a) Seaward of the barrier systems the _inter-tidal sand flat zone_ has the largest areal extent of any depositional area but varies considerably in width, being widest (1.75 km) north of Stiffkey, narrowest (0.25 to 0.4 km) from Thornham to Scolt Head Island, and essentially non-existent in front of the Blakeney Point spit.

Two main types of depositional environment can be recognised in the inter-tidal flats; areas of mainly sand-sized sediment on which the megaripple fields and beach bars develop, and areas of poorly sorted sand with a fine component, often in the form of mud drapes or flasers, which develop in the shelter of high beach bars or in areas with a low gradient remaining partially waterlogged at low tide.

Beach profiles on this coast have been shown to vary with gravel content (Clayton, 1977), a high content resulting in a steep gradient, and hence a small inter-tidal area, and a low gravel content giving a low gradient and large area of inter-tidal flats.

Between Wells and Stiffkey recently-formed Lower Marsh deposits extend seaward of a low gravel ridge barrier. Initial salt marsh colonisers, Spartina townsendii (Townsend's cord grass) and Aster tripolium (sea aster), have encouraged the deposition of silts and muds, gaining protection from well developed beach bars and an extensive low gradient sand flat.

At the western end of the study area steeper beach profiles and localised shoreface erosion have exposed areas of older Holocene salt marsh and Phragmites peat deposits which, north of Titchwell, support an in situ remnant pine forest at -1.25m O.D.

b) Landward of the barrier systems an extensive salt marsh zone has developed. Over a large proportion of the area these are drained by major creeks flowing parallel with the coast, entrained in this direction by the drainage limitations imposed by the barriers. Creek morphology and drainage characteristics have been described by Bayliss-Smith et al. (1979).

In areas of upper marsh development peat deposits are currently forming under Phragmites reed beds whilst salt marsh mud deposits occur in areas of Upper and Lower Marsh. In several areas older barrier ridges entrapped by progradational deposition are visible as elevations above the surrounding marsh level, recognition of which is enhanced by variations in the vegetation cover.

Where inter-tidal deposits are protected behind recurved spits at the western end of Blakeney Point and Scolt Head Island complex associations of muds and sands occur with gravel patches in the major back barrier channels.

c) Forming an almost continuous partition between (a) and (b) are the barrier and spit systems (Fig. 5) which all contain a high proportion of gravel.

Spits are represented in two areas, Blakeney Point and Scolt Head Island, although the latter is now discontinuous with its apparent original source area. Both areas possess evidence of westerly migration in the form of abandoned lateral ridges which often have large superimposed dunes. The main ridge of Scolt Head Island also possesses dunes, which are absent along most of the Blakeney ridge due to an inadequate sediment supply area.

Barriers present in the rest of the area vary in morphological form, the largest being those to the east and west of Holkham Gap where dunes reach a height of 15m. Two basic forms of small barriers can be recognised conforming in their dimensions to Hoyt's (1969) description of cheniers. Low gravel barriers with a height up to 2m above the surrounding marsh, occasionally with dunes up to 5m, are present between Wells and Blakeney. However, recently formed small barriers such as Thornham West Island have a continuous cover of dunes up to 10m with their morphology reflecting the shape of the beach bars from which their development can be traced during the present century (Chapman, 1948).

## DISCUSSION

### 1. Sediment distribution and transport

Spatial trends in grain size distributions in this area follow three patterns. Sediment with a mean size smaller than 4ø increases in mean grain size with increasing marine wave influence due to more frequent and intense resuspension of sediment which

Pearson, Funnell and McCave

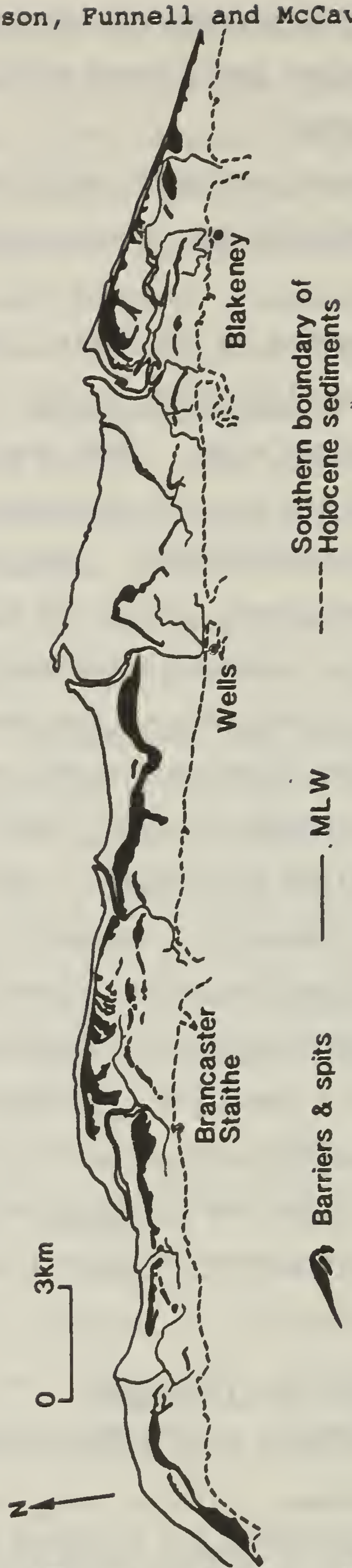

Figure 5 Location of present and remnant barrier and spit systems visible from surface indications.

removes material finer than 4ø and prevents its accumulation. Two spatial trends in sand sized sediment have been demonstrated. Mean size decreases from backbeach, through inter-tidal to offshore areas whilst sorting decreases in the same direction (Roy, 1967; McCave, 1978). There is also a weak trend of increase in the mean grain size of the sand fraction towards the west ($r = 0.497$, $p = 0.05$). This McCave (1978) ascribes to westerly longshore transport with continuous winnowing and removal of the finer sand fraction into the offshore zone leaving a progressively coarser residual deposit.

The distribution of gravel is of importance due to its influence on inter-tidal flat morphology. Gravel occurrence is restricted to two main areas (Blakeney spit, from Weybourne to Blakeney Point, and Scolt Head Island) although its contribution is larger on Blakeney spit (Bhattacharyya, 1967; Roy, 1967).

The source of gravel has long been a contentious issue. Reid (1907) suggested that sediments on the North Norfolk coast were reworked fluvial deposits from 'an ancient east and west river'. Steers (1960) gradually developed his ideas into a two-fold hypothesis involving longshore transport from the cliffs east of Weybourne and some movement of material from offshore.

However, gravel transported from the eastern end of the area is not transported past the western end of Blakeney Point, attested to by the relative absence of gravel ( 5%) between Wells and Stiffkey, and the variations in clast composition between the eastern and western ends of the area (Coles-Phillips, 1960; Battacharyya, 1967). These variations correspond to differences in the clast composition of glacially derived material (Straw, 1960) and suggest separate, local, sources at either end of the area.

Models of sediment movement along the East Anglian coast calculated from beach volume changes (Clayton, 1977) and wave refraction data (Vincent, 1980) show a net westerly movement of material. Clayton shows a net sand transport of 70 x $10^3$ $m^3$ $yr^{-1}$ along the Blakeney spit with 40 x $10^3$ $m^3$ $yr^{-1}$ in the west of the area. Figures from Vincent for the Blakeney Point area are difficult to evaluate as they represent the potential sand transport rates which are in excess of the actual transport rates in areas of low sand availability, or in this case, areas of predominantly gravel size material.

Longshore movement of the gravel on Blakeney spit has been demonstrated by a reduction in clast size from east to west (Hardy, 1964). A map dated 1586 (Cozens-Hardy, 1924) shows the western end of Blakeney Point to be opposite Blakeney Village, hence it has migrated some 3 km west in the past 400 years. The lateral ridges become progressively shorter towards the east due to landward migration of the main ridge by washover processes which Cozens-Hardy (1924) estimated at 0.91m $yr^{-1}$ for the previous 275 years.

Scolt Head Island has also migrated westwards and possesses the same basic features except that it is separated from the tidal flats at its eastern end by a channel. Shoreward migration is also indicated by shorter lateral ridges at the eastern end and exposure of marsh muds on the seaward beach face. Any lateral ridges existing to the east of the eastern channel have been eroded or buried by the present dune system.

Whilst retreat of Blakeney Spit and Scolt Head Island is caused by washover processes, the shoreface erosion west of Brancaster is produced within a local sedimentation cell (Cambers, 1975) where material is transported eastwards into the area behind Scolt Head Island and gives rise to ridges recurved in a direction opposite to the main longshore transport direction. This is due to the local dominance of N. and N.W. waves, the effect of the more common N.E. waves being blocked by the western end of Scolt Head Island (Roy, 1967).

Apart from these three areas the remainder of the coast is apparently prograding at the present time.

## 2. Succession of Environments

From the aerial photographic analysis and environmental definitions presented previously, together with historical data, it is possible to define in general terms the successional development of environmental types.

The succession starts with the development of inter-tidal sand flats whose gradient and width are controlled by the amount of gravel present.

Initiation of a series of beach bars is important to the subsequent development of other environments. These bars form on the shoreface and gradually migrate shorewards, increase in height and preferentially accumulate gravel-sized material. At a point seaward of the existing high water mark, when the bar has reached a height sufficient for subaerial exposure on all but the highest tides, it is stabilised by the growth of marram grass (Ammophilia arenaria) (mainly in the summer period between spring and autumn equinoxes) which traps wind blown sand around its base to produce a dune system.

This process can be seen occurring at the present day on the inter-tidal flats N.W. of Holkham Gap (Fig. 3) where a small beach bar had already developed dunes in 1969. The large bar to the N.E. of this has, since the aerial photographs were taken, stabilised in this position and developed an extensive dune system up to 6m above the surrounding area.

The two large barrier dune systems to the east and west of Holkham Gap appear equally mature. However, those to the west have been dated from indirect archaeological evidence to at least 2000 B.P. (Pethick, 1980). Those to the east are not shown on a detailed map of 1722 when only accreting salt marsh was present. It is reasonable to suppose that the dune system existed in incipient form as a beach bar. By 1780 this beach bar had developed into a high dune system. Holkham Gap at this time was still a tidal inlet with outflow through the Wells Channel.

The extensive dune barrier at Holme, shown in Milnes' map of Norfolk in 1579 (Marsh, 1915) has also prograded seawards since 1935 by the addition of a new dune ridge. Wind-blown sand infilling between the ridges has now made this continuous with the old ridge system.

The development of beach bars of sufficient height controls the amount of wave energy reaching inter-tidal areas in their lee. Tidal outflow from these protected areas produces channels parallel to the beach bar crests which are the incipient forms of the major transverse back-barrier creeks characteristic of salt marsh drainage along this coast.

Adjacent to these shallow tidal outflow channels the inter-tidal flats accumulate thin drapes of silt and mud-sized material. Algal binding rapidly increases their resistance to tidal erosion and promotes accretion until the relative height of the sediment surface allows colonisation by Lower Marsh plants, as at Thornham West Island where plant colonisation has progressed considerably since the initial survey of Chapman & Steers in 1935 (Chapman, 1948). At this period creek formation reaches a more advanced stage with the major channels of the subsequent Upper Marsh being developed. Initially sedimentation rates are high (c. 17 mm $yr^{-1}$)

although these decrease as the marsh surface becomes higher and is subjected to less frequent inundation (Pethick, 1981). The progressive development of the salt marsh surface is reflected by a change in plant community structure (Chapman, 1960) until the fully developed Upper Marsh surface is reached between +2.6m and +2.8m O.D. At this stage sedimentation rates are low (c. 1 mm $yr^{-1}$) with high tides augmented by storm surges being the major sediment depositors introducing coarse material to the marsh surface (Carling, 1982) and also being the only type of tidal flow liable to produce a geomorphic effect on the marsh creeks (Bayliss-Smith et al. 1979).

## CONCLUSIONS

When extrapolating over short time periods the unknown factors which can influence interpretations of older deposits using uniformitarian principles are not encountered. Therefore precise comparisons can be made between surface depositional environments and older Holocene deposits within limited geographical areas. Here we have presented a basis which uses both large and small scale surveys to define environmental units by utilizing ecological parameters (vegetation and microfauna) in addition to the standard sedimentological definitions. On present day salt marsh and barrier systems vegetation is a major controlling factor influencing deposition and subsequent geomorphology. The recognition of vegetation type from aerial photographs allows us to distinguish some of the major depositional environments over a large area without the need for extensive ground surveys.

By applying the same microfaunal and sedimentological tests to subsurface Holocene deposits encountered in the same area as the surface deposit survey it is possible to define the environment of deposition more precisely than by the use of sedimentary parameters alone. The additional information gained in this way also permits a more detailed picture of environmental succession and ecological development to be obtained allowing greater clarity in defining the recent geological history of the area.

## ACKNOWLEDGEMENTS

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Editor's note: The ø (phi) measure of grain size corresponds with the millimetre sizing as follows:

0ø = 1mm
1ø = 0.5mm
2ø = 0.25mm SAND
3ø = 0.125mm = 125μm
4ø = 0.063mm = 63μm - - - - - - - - - - -
5ø = 0.031mm = 31μm
6ø = 0.016mm = 16μm SILT
7ø = 0.008mm = 8μm

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# PALAEOECOLOGY OF THE MOLLUSCA OF THE CRAG OF BULCAMP, SUFFOLK

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Counts were made, following the methods of Norton (1967), on 3 kg air-dried samples, supplied by P.G. Cambridge, from the western trench of the excavation. The results, summarized in Table 1, demonstrate that the fossiliferous sandy sediments at Bulcamp contain an abraded, allochthonous shell deposit from mixed habitats; a situation typical of the Norwich Crag. *Spisula subtruncata* and the extinct *Macoma praetenuis* dominate an assemblage of juvenile and adult bivalves mostly originating from sublittoral muddy or silty habitats. However, the deposit formed sufficiently near to the coastline to receive a significant contribution from tidal flats, including most of its low complement of gastropods. Presumably *Littorina* spp. and *Mytilus edulis* lived on stable portions of these flats or on stones. Few of the extant species would have inhabited the sand in which the shells are now preserved; *Natica* spp. being the most likely. As it is predatory this genus is never present in high frequencies and if its prey consisted of extinct forms contributions from sandy sublittoral habitats may be underestimated. At Bulcamp borings by *Natica* are most common in adult *Macoma praetenuis* and juvenile *Spisula subtruncata*.

There is no evidence for any change of facies in the section. Differences between samples are probably due to changes in current velocity and the resultant sorting of shells. This effect is most marked in the top sample (+ 4.6 m O.D., of Funnell 1983) which contained many large, specifically determinate specimens, including an increased proportion of intertidal and sublittoral gastropods; but fewer small (< 1.6 mm) shells (c. 260 individuals $kg^{-1}$) than samples lower in the section (c. 420 individuals $kg^{-1}$ as small shells). The upward increase in the proportion of *Macoma praetenuis* and the accompanying fall in *Spisula subtruncata* may have a similar explanation but are not simply a statistical effect as there are parallel changes in numbers of these species. *M. praetenuis* more than doubles from 131 $kg^{-1}$ at the base to 281 $kg^{-1}$ at the top while the combined total of *S. subtruncata/S.* sp. declines from 518 $kg^{-1}$ to 325 $kg^{-1}$.

The intermediate sample at + 3.1 m O.D. differed from the others in containing more numerous, often rolled, iron-stained pieces of hardened clay or silt and in being apparently more subject to decalcification. The clay or silt fragments usually carried superficial shells or fragments but contained no recognizable fossils when broken open. Similar hardened fine sediments occasionally infill gastropods including non-marine forms, hinting that some of these may be reworked. The source of this material may have provided surfaces for epifauna; there were nearly three times as many barnacle valves in this sample as in those above or below. Shells at this level were sometimes partially eroded or cemented together by redeposited calcium carbonate, while numerous very small, irregular limey tubes were present. Decalcification may have selectively affected small, fragile forms such as *Hydrobia*, accounting for their low incidence in the sample.

Virtually all the species in the samples, and most additional finds, occur in the Bramerton sections (Funnell, Norton and West, 1979). Furthermore the fauna has a less diverse, sublittoral element than Antian samples from Covehithe Warren (Long, 1974) where *Spisula* *elliptica* greatly outnumbers *S. subtruncata*. Accordingly Bulcamp is best compared to Bramerton and sites in Suffolk (West and Norton, 1974) now considered to be of comparable age. Not surprisingly there is no exact match to any other site or sample, not even to nearby Wangford. The closest analogy is a composite one to zone BM 2 of Norton (1967); the upper shell bed and some sparsely shelly material just above it at Bramerton Common pit. This has been described (Norton, 1977) as a boreal to subarctic open coast facies. The Bulcamp assemblages are consistent with this view in the regular presence of *Yoldia myalis* and *Macoma calcarea* (too few to be tabulated), but species such as *Astarte semisulcata* and *Serripes groenlandicus* are either very rare or absent. The latter species is a common member of the restricted arctic community in the Baventian at Covehithe (West, Funnell and Norton, 1980). The molluscs at Bulcamp thus indicate a marine climate cooler than the present southern North Sea but not as cold as that reached in the Baventian. It is impossible to say whether this would be at the beginning or the end of a temperate stage. Unlike parts of the Bramerton sections there is no evidence for environmental restraints on molluscan growth; on the contrary some examples of *Yoldia myalis*, *Macoma calcarea* and *M. obliqua* are exceptionally large and thick-shelled for the Norwich Crag.

Non-marine molluscs were found in all samples at a frequency of around 1 in 1,000 individuals; this hardly justifies describing the shell deposit as 'fluvio-marine'. Remains of other invertebrate groups, indicated in the faunal list, occurred in all samples but only cirripede valves were numerous (up to 850 $kg^{-1}$). Fish and small mammal bones or teeth were also scattered throughout at low frequencies.

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Bulcamp Mollusc Palaeoecology

| Category | Main Contributors | % Total Individuals in Samples | | |
|---|---|---|---|---|
| | | (+4.6m O.D.) | (+3.1m O.D.) | (+2.1m O.D.) |
| | | S.1 | S.3 | S.2 |
| Freshwater and land. Includes extinct *Viviparus medius*. | | 0.09 | 0.11 | 0.06 |
| Intertidal. Epifauna on firm surfaces. | | 9.64 | 4.84 | 5.85 |
| | *Littorina littorea* | 2.00 | 0.48 | 0.56 |
| | *Littorina* sp. | 1.92 | 1.05 | 0.27 |
| | *Mytilus edulis* | 2.11 | 0.76 | 1.95 |
| | Mytilid indet | 3.24 | 2.29 | 2.51 |
| Intertidal. Sandy flats ("wadden" habitats). | | 10.18 | 8.35 | 11.52 |
| | *Hydrobia* spp. | 3.05 | 1.28 | 3.08 |
| | *Retusa obtusa* | 0.52 | 0.50 | 0.72 |
| | *Scrobicularia plana* | 0.46 | 0.60 | 0.45 |
| | *Cerastoderma edule* | 4.12 | 1.26 | 2.11 |
| | *Cerastoderma* sp. | 2.00 | 4.69 | 4.97 |
| Intertidal to shallow sublittoral. Sand/mud. | | 0.36 | 0.68 | 0.48 |
| | *Mya* sp. | 0.18 | 0.68 | 0.27 |
| Sublittoral. Mud/silt; infauna | | 33.76 | 45.45 | 47.62 |
| | *Nucula* sp. (aff. *tenuis*) | 0.31 | 1.38 | 1.47 |
| | *Yoldia myalis* | 1.22 | 0.43 | 0.56 |
| | *Yoldia* sp. | 2.35 | 1.81 | 2.06 |
| | *Spisula subtruncata* | 21.32 | 16.81 | 23.02 |
| | *Spisula* sp. | 8.19 | 24.85 | 20.35 |
| Sublittoral. Mud without stones. | | 0.18 | 0.24 | 0.37 |
| Sublittoral. Muddy, coarse; infauna. | | 0.03 | nil | 0.14 |
| Sublittoral. Clean, coarse sediments. | | 0.67 | 1.07 | 0.85 |
| | *Lepton nitidum* | 0.52 | 0.97 | 0.69 |
| Sublittoral. Epifauna/boring. | | 0.24 | 1.00 | 0.48 |
| | *Hiatella 'rugosa'* | 0.24 | 0.76 | 0.24 |
| Sublittoral. Sandy sediments. | | 0.94 | 0.28 | 0.29 |
| | *Natica* spp. | 0.70 | 0.17 | 0.13 |
| Extinct | | 27.56 | 14.60 | 11.87 |
| | *Potamides tricintus icenicus* | 1.01 | 0.31 | 0.56 |
| | *Macoma obliqua* | 1.04 | 0.10 | 0.21 |
| | *Macoma praetenuis* | 25.27 | 14.14 | 11.02 |
| Not assignable | | 16.00 | 23.28 | 20.14 |
| | Indet. gastropods | 2.32 | 1.83 | 2.14 |
| | *Macoma* spp. | 6.42 | 9.71 | 7.38 |
| | Indet. bivalves | 6.45 | 10.45 | 9.76 |

| Category | Main Contributors | % Total Individuals in Samples | | |
|---|---|---|---|---|
| | | (+4.6m O.D.) | (+3.1m O.D.) | (+2.1m O.D.) |
| | | S.1 | S.3 | S.2 |
| | Not specifically determined | 39.02 | 62.65 | 56.56 |
| | Total gastropods | 13.14 | 7.24 | 9.17 |
| | Total bivalves | 86.86 | 92.76 | 90.83 |
| | Individuals $kg^{-1}$ air dry sediment | 1,113 | 1,384 | 1,193 |

Table 1. Quantitative Molluscan Palaeoecology.

(Main contributors constitute 0.5% of all individuals in at least one sample. Where incompletely determinate forms can be assigned to a habitat they are placed there. *Hydrobia* spp. includes specimens which might be specifically identified. *Scrobicularia plana*, *Lepton nitidum* and *Potamides tricinctus icenicus* include some very worn examples. Less common species found in the samples, but not given here, are indicated in a faunal list.)

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# OSTRACODS FROM THE CRAG OF BULCAMP, SUFFOLK

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Ostracods are small bivalved crustaceans, in which the paired appendages associated with the group are inside the valves and extend ventrally from between two calcified valves which together comprise the animals carapace. In common with related animals, ostracods grow by a moulting process and for one animal there can be a number of discarded valves that are potential fossil material. For taxonomy it is important to distinguish adults from juveniles (called instars) which may differ morphologically; adults of different species range in size from 0.3 mm to 0.5 - 0.7 mm and exceptionally may exceed 1 mm in length. The appendages are only rarely preserved and palaeontologists study the calcified valves, which occur commonly in washed residues with foraminifers. Ostracods are known from Cambrian times onwards and were exclusively marine until the Carboniferous when they colonised non-marine environments. At the present day ostracods inhabit all aquatic habitats from the deep ocean basins to rivers, temporary pools, hot springs and even wet moss. Most fossilised ostracods were bottom dwelling and this feature combined with their widespread distribution in marine and non-marine waters makes them very useful for the investigation of past environments. An excellent ostracod-based environmental interpretation of the West Runton Freshwater Bed of the Cromer Forest Bed Formation has been made by De Deckker (1979). Ostracods are also useful for biostratigraphic purposes. For example, the 'Purbeck-Wealden' (Upper Jurassic to Lower Cretaceous) sediments of southern England are zoned with some accuracy by non-marine ostracods; indeed, the original zonation dates from 1850 and was probably the first use of ostracods for this purpose.

Crag ostracods have been almost entirely neglected since the classic and pioneer studies of Professor T. Rupert Jones, and the available literature totals four works (Jones, 1856; Jones, 1870; Bell and Bell, 1872; Jones and Sherborn, 1889), although a new study of Coralline Crag assemblages has recently been completed (Wilkinson, 1980). Ostracods from the Crags are now being studied by Dr D.J. Horne, including material from the Ludham and UEA-series boreholes already examined for foraminifers, pollen and molluscs by Professors Funnell and West and their associates.

In the present study the same levels were sampled for ostracods as for foraminifers (Funnell, 1983). Notice that the ostracods were much less numerous than foraminifers in the samples, a common phenomenon.

| | Sample A | 1 | 3 | 5 |
|---|---|---|---|---|
| *Pontocythere elongata* (Brady) | 11v | 1v | 5v | 1c,8v,1f |
| *Sarsicytheridea bradii* (Norman) | 2v | | | |
| *Ilyocypris gibba* (Ramdohr) | 1v | | | |
| ? *Ilyocypris* sp. | 1v | | | |
| *Hemicythere* cf. *H. villosa* Sars | 1c,1v,?1f | | | |
| *Cythere lutea* O.F. Müller | 1v | | | |
| *Cyprideis* cf. *C. torosa* (Jones) | | | | 1v |
| Unidentifiable fragments | 4f | | | |
| Totals | 1c,17v,5f | 1v | 5v | 1c,9v,1f |

c = carapace v = valve f = fragment

Of the samples examined only 4 contained ostracods and the assemblages were small and rather disappointing. Preservation was similar in each sample, with the specimens ironstained and slightly worn.

The species present are all alive today and reflect a variety of environments, viz. *P. elongata, S. bradii, C. lutea* and *H. villosa* are marine, shelf species, and the *C.* cf. *torosa* is smooth and indicative of similar salinity conditions (as opposed to the nodose form which is, debatably, associated with reduced salinity waters). *Ilyocypris gibba* is a freshwater to oligohaline (brackish) species washed into a marine situation. In many ways the assemblage is similar to those found in the outer Thames Estuary at the present day, with freshwater *Ilyocypris* washed into a shallow marine fauna which is itself indicative of a sandy substrate.

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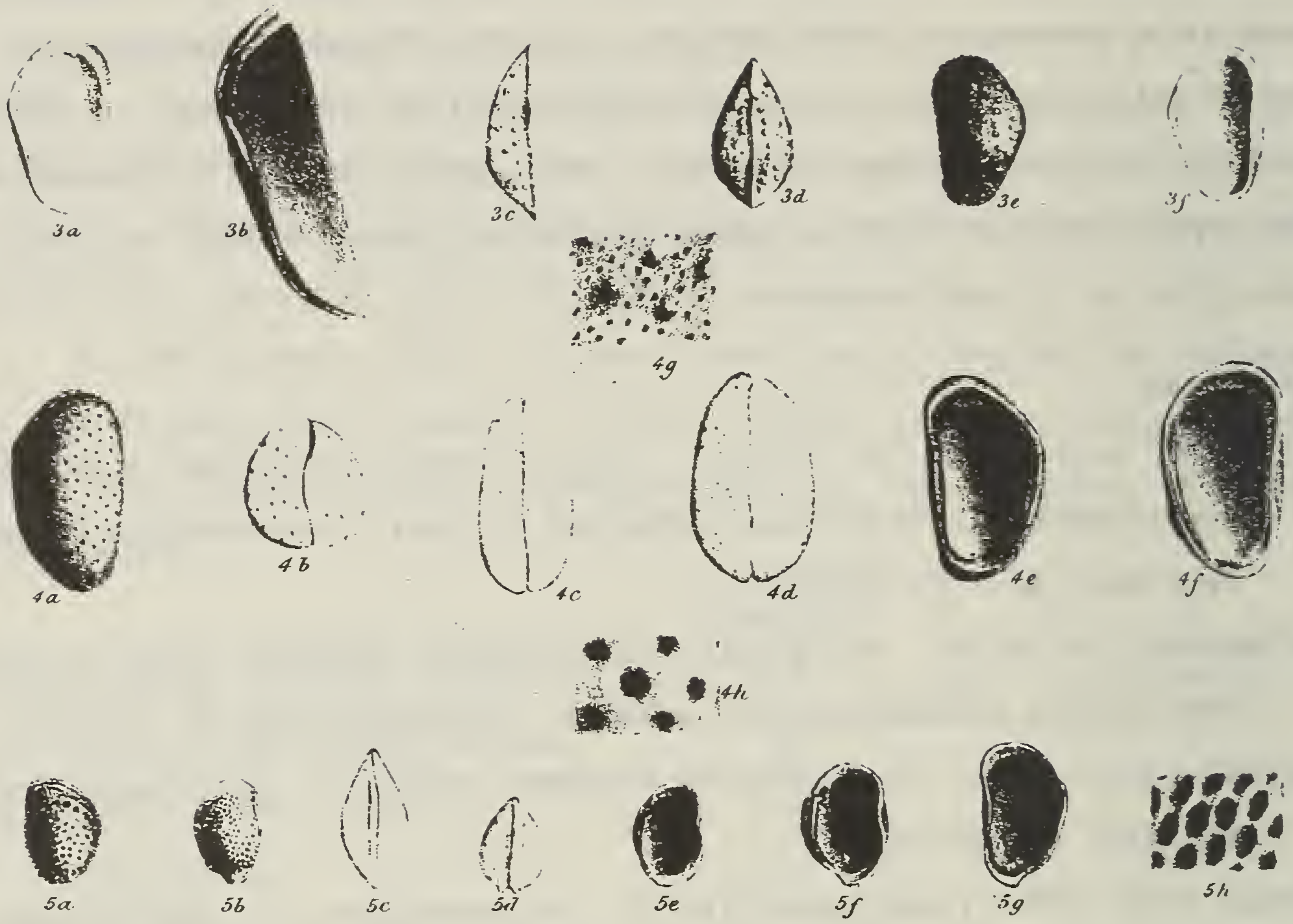

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# NON-MARINE MOLLUSCA FROM THE CRAG OF BULCAMP, SUFFOLK

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The following list tabulates the non-marine Mollusca from Bulcamp Union Farm (TM 442755). It is based partly on literature records, checked against actual museum specimens wherever possible, but mostly on recent collections made by P.G. Cambridge and Dr P.E. Long.

**Freshwater species**
*Viviparus medius* (S. Woodward)
*Valvata piscinalis* (Müller)
*Bithynia cf. tentaculata* (Linné)
*Neumayria cf. priscillae* Girotti
*Lymnaea palustris* (Müller)
*Lymnaea peregra* (Müller)
*Planorbis planorbis* (Linné)
*Anisus leucostoma* (Millet)
*Planorbarius corneus*(Linné)
*Ancylus fluviatilis* Müller
*Sphaerium corneum* (Linné)
*Pisidium amnicum* (Müller)
*Pisidium casertanum* Poli (including var. *ponderosum* Stelfox)

**Brackish species**
*Hydrobia ventrosa* (Montagu) aggregate
*Hydrobia ulvae* (Pennant)
*Ellobium pyramidale* (Sowerby)

**Terrestrial species**
*Succinea oblonga* Draparnaud
*Succinea/Oxyloma*
*Trichia hispida* (Linné) aggregate

This fauna is a mixture of freshwater, brackish and terrestrial elements indiscriminately brought together in a shelly sand composed almost exclusively of marine molluscs. Little can be said regarding the palaeoenvironment since there is no certainty that these shells were derived from a single source. Most are common palaearctic species that are known from both cold and temperate stages and all, except *N.* cf. *priscillae*, *A. fluviatilis* and *S. corneum*, have been found at other Norwich Crag sites. Three taxa deserve special mention.

*Viviparus medius* is an extinct prosobranch characteristic of many British Early Pleistocene sites. There are several other Norwich Crag records and at least one from the Red Crag. It is unknown from the Middle and Late Pleistocene in Britain.

*Sphaerium.* Two species appear to be present at Bulcamp - a worn valve that seems to be typical *S. corneum* and six valves that belong to another species, which has a more quadrilateral outline and much stronger striation. This form cannot be matched with any living species and it has recently been described and named as *Sphaerium icenicum* by Holyoak & Preece (1986). This species is also known from the Norwich Crag at Sizewell (Preece, 1988), Thorpe and Bramerton Common. It has not yet been recognized in comparable deposits in the Netherlands, where other extinct species of *Sphaerium* are known (T. Meijer, personal communication).

*Neumayria.* At least two species of bithyniid prosobranchs are represented. One appears to match modern shells of *Bithynia tentaculata* but much of the fossil material is fragmentary and can only tentatively be referred to this species. A second species is much larger and more loosely coiled with a thicker shell. Comparison with continental material leaves no doubt that the latter belongs to forms currently assigned to the genus *Neumayria* De Stefani, a form hitherto unrecognized in the British Quaternary.

Illustrations and a full discussion of the Bulcamp *Neumayria* have been given elsewhere (Preece, 1990). All we need to note here is that the Bulcamp specimens have been provisionally referred to *N. priscillae* Girotti, a form known from the Miocene/Pliocene to Late Villafranchian in Italy and from sites of similar or slightly later date in France and the Netherlands. From the presence of *Macoma praetenuis* and absence of *M. balthica*, it would appear that the Bulcamp deposits correlate with the Dutch Middle Tiglian (cf. Meijer, 1988). The presence of *N. priscillae* at Bulcamp therefore matches its known stratigraphical range in the Netherlands.

I thank Philip Cambridge and Peter Long for allowing me to work on their material and Tom Meijer (Rijks Geologische Dienst, Haarlem) for his helpful comments on the Bulcamp *Neumayria*.

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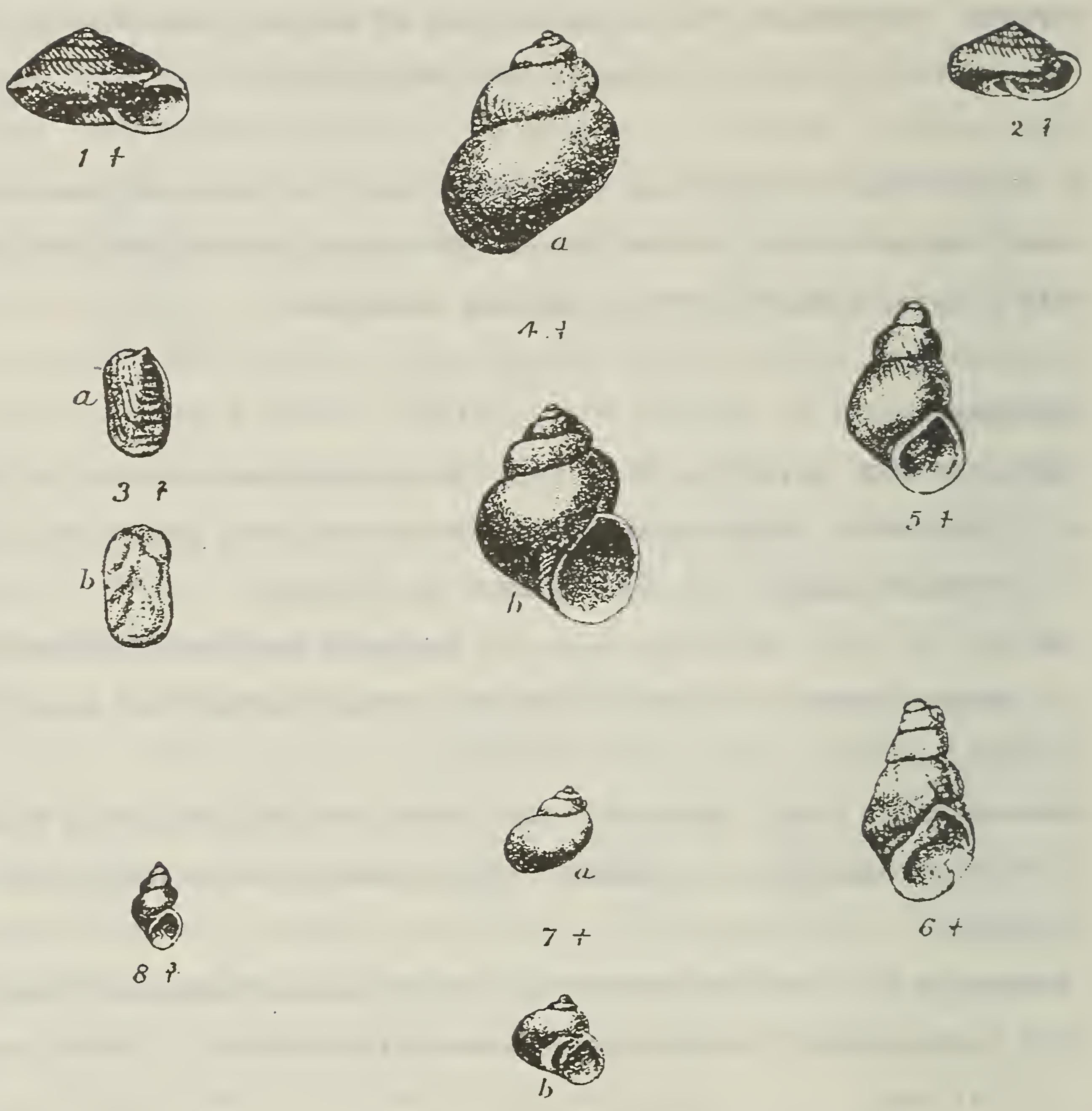

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# SMALL MAMMAL REMAINS FROM EARLY PLEISTOCENE CRAG AT BULCAMP, SUFFOLK

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## ABSTRACT

Small mammal remains have been recovered from shelly sands exposed in section at Union Farm Pit, Bulcamp, Suffolk (TM44207545). The following taxa are recognised: *Desmana thermalis*, *Micromys* sp., *Mimomys pliocaenicus*, *Mimomys newtoni*, *Mimomys reidi*, *Mimomys altenburgensis*, *Desmana* and *Micromys* have not previously been recorded from deposits of this age (Norwich Crag) in England. The assemblage belongs to faunal group 2 of Mayhew and Stuart (1986) and suggests a Bramertonian age for the Bulcamp crag deposits. Faunas of similar composition are known from the Tiglian and Villanyian stages of Continental Europe.

## INTRODUCTION

The Crag deposits of East Anglia have attracted attention for many years, but their relative and absolute ages are still under discussion. In the last century, emphasis was given to lithostratigraphic evidence supplemented by studies of the Mollusca. More recently, this has been supplemented by studies of foraminifers and pollen. In the last few years attention has been given to the small mammal remains from the Crags (Mayhew & Stuart 1986), and this evidence seems to offer significant potential in resolving uncertainties in interpretation arising from other lines of research.

This paper describes a small mammal fauna from the Norwich Crag of Bulcamp Union Farm Pit, near Blythburgh, Suffolk. The assemblage from Bulcamp is the largest collection of small mammal remains so far obtained from a Norwich Crag locality and forms a good reference point for comparison with other faunas. The conclusions given here indicate that the Bulcamp deposits are similar in age to those in the lower part of the section at Bramerton (Blake's Pit), type locality for the Bramertonian Stage(Funnell et al. 1979).

## LOCALITY DETAILS, TAPHONOMY AND DATING

Bulcamp Union Farm Pit is situated at TM44207545, south-south-west of the farm buildings just above the river Blyth floodplain, on the south facing valley side, across the river from Blythburgh, Suffolk. The pit was noted in 1871 by Prestwich, but thereafter became rapidly obscured (Reid 1890). The pit was reopened in 1979 by the Geological Society of Norfolk, assisted by the Geological group of Ipswich (Cambridge 1982). The author visited the locality in the summer of 1980.

Details of the sections are provided by Funnell (1983). Two sequences were exposed, each consisting of about 3 metres of sands with abundant shells. Underlying one of these sequences were unfossiliferous sands (about 3 metres excavated). The deposits are interpreted as being entirely marine.

The vertebrate samples were taken separately in 1979 and 1980 by three persons - Dr Peter Long, Mr Philip Cambridge, and the author - from the upper three metres of the section containing shells. Samples at different levels are combined for this study. In total, 80 identifiable teeth and bones of small mammals have been recovered.

In addition to the vertebrate material described in the systematic part of this paper, the Bulcamp deposits have yielded: fish bones and teeth; amphibian bones; bird bones and mammal bones (phalanges, limb bones, mandible fragments). The preservation is in general good, although some of the teeth of voles are eroded in the manner described by Mayhew (1977). This appearance is thought to be due to digestion by birds of prey before fossilisation. The terrestrial vertebrate remains are consistent with the sort of material found in bird of prey pellets and in the droppings of carnivorous mammals.

The vole teeth are darkly stained, but are not heavily mineralised or rolled. I conclude that they have not been transported over large distances and have not been reworked from much earlier deposits. There is no evidence of mixing of different aged faunas, and similar microtine species occur together in assemblages from the loess in Austria (Rabeder 1981: Stranzendorf) in which no reworking is postulated.

In conclusion, the assemblage described here is taken to represent part of the fauna during the time of deposition of the sediments at Bulcamp. It resulted in part from the activities of carnivorous birds and mammals. The excellent preservation may be due to the inshore/intertidal nature of the Bulcamp deposits (Funnell 1983). Similar conditions existed during at least part of the sedimentation cycle at Bramerton (Funnell, Norton & West 1979) where similarly well preserved material of small vertebrates has been obtained.

Studies of the Foraminifera and molluscs (Funnell 1983) indicated temperate climatic conditions, with an inner sub-littoral to intertidal environment. No significant differences in fauna were found between the various levels sampled in the sections. The foraminifers and molluscs from Bulcamp indicate that these are Norwich Crag deposits (Funnell 1983). It was not possible on these lines of evidence to date the locality more precisely. Correlation with either

Antian (corresponding to the lowest shell beds on the coast at Easton Bavents, underlying the type Baventian deposits) or Bramertonian (lower shell bed at Bramerton) was thought possible. The conclusion from the present study is that the Bulcamp deposits are identical in age to those of Bramerton (lower shell bed at Blake's Pit) on the basis of the contained microtine rodent faunas.

No rodent remains are know from the Antian of the Ludham borehole. The fauna of the shell beds underlying the Baventian of Easton Bavents and Covehithe is under study; preliminary results indicate that it differs from that of Bulcamp.

## SYSTEMATIC SECTION

### Insectivora

Talpidae. Fischer de Waldheim 1812

*Desmana thermalis* Kormos 1930 (pl. 1, fig. 11)

Material: fragmentary r. mandible lacking teeth PGC17.

Comments: Two species of desman are known from deposits of roughly similar age at Tegelen, the Netherlands (Rümke 1985). The larger species is referred to *Desmana thermalis* Kormos, and the smaller species to *Galemys kormosi* (Schreuder 1940). The mandible from Bulcamp is most similar to the larger species from Tegelen.
This represents the earliest occurrence of *Desmana* from Britain. *Galemys kormosi* is also recorded from the crag deposits at West Runton, Norfolk (Pre-Pastonian, Stuart 1982) and Sidestrand, Norfolk (Harrison et al. 1988). Remains from the much later Cromerian deposits at West Runton, and from Westbury-sub-Mendip, Somerset (Bishop 1982) appear to be very similar to the Russian desman, *Desmana moschata*.

## Bulcamp Small Mammals

Rodentia

Muridae. Gray 1821

*Micromys* Dehne 1841

*Micromys* sp. (pl. 1, fig. 10)

Material: 1 upper l. incisor PL23

Comments: The incisor is flattened in cross-section and the dimensions of the tooth are similar along the total length (i.e. not juvenile). There is no notch on the wear surface. The width of the cross-section is 0.3mm and the length 1.0mm. The tooth does not represent a juvenile of *Apodemus* or *Mus* and is indistinguishable from recent *Micromys minutus* (harvest mouse) from the Netherlands. Specific determination is left open pending recovery of other dental elements.

Arvicolidae Gray 1821

(Note: unless otherwise stated, the measurements given refer to the length and width of the wear surfaces of the molar teeth. The measurements were taken with a Leitz ortholux microscope reading to 0.01mm.)

*Mimomys pliocaenicus* Major 1902

(pl. 1, figs 8, 9, 12; pl. 2, figs 4-10; pl. 3, figs 9-13; pl. 4, figs 7-10; pl. 5, figs 6, 7)

Material: (upper molars) 10 M1, 8 M2, 5 M3, (lower molars) 4m1, 3 m2, 3 m3.

Measurements: M1 - 2.90 x 1.63, 2.80 x 1.62, 2.76 x 1.55, 2.87 x 1.61, 2.90 x 1.75, 2.80 x 1.50, 2.87 x 1.78, 2.88 x 1.72; M2 - 2.18 x 1.40, 2.21 x 1.51, 2.28 x 1.48, 2.22 x 1.24, 2.32 x 1.40, 2.08 x 1.37, 2.27 x 1.58; M3 - 2.24 x 1.25, 2.04 x 1.11, 2.20 x 1.12, 2.32 x 1.28, 2.23 x 1.18; m1 - 3.30 x 1.48, 3.52 x 1.62, 3.00 x 1.20; m2 - 2.21 x

1.42, 2.37 x 1.52; m3 - 2.02 x 1.19, 1.98 x 1.14.

Comments:

a) Number of roots: In the upper first molars, seven have three roots, one has two roots and the remaining two are too damaged to determine. Two of the upper third molars are two-rooted and one is three-rooted. This is similar to the situation in samples from Thorpe and Bramerton (Mayhew & Stuart 1986).

b) Crown height: The height of the enamel free areas is indicated on the figures of the teeth (see plates). In general the enamel free area height resembles that of the teeth of *M. pliocaenicus* from Bramerton. A comparison of crown height between Bulcamp and some other localities is given in figures 1 and 2 (pp. 74 & 75).

Figure 1 compares the timing of disappearance of the enamel islet in the lower first molars of *M. pliocaenicus* in relation to the crown height in various samples. The comparison suggests that the Bulcamp material more closely resembles samples from Thorpe and Bramerton (faunal group 2 of Mayhew & Stuart 1986) than samples from East Runton and West Runton crag (faunal group 1).

In figure 2, the heights of the enamel free areas in the upper third molars of *M. pliocaenicus* from various localities are compared. Although the material is very limited, clear differences can be seen between samples from older and younger localities. The Bulcamp material is again more similar to that from Bramerton than that from West Runton and East Runton. The Bulcamp and the Bramerton material is lower crowned than material from the boring Zuurland at 95m (Tiglian C 4c) and Tegelen (Tiglian C 5) from the Netherlands. The limited material available from Sidestrand appears to indicate a high crowned, advanced assemblage.

c) Overall size: The measurements indicate an overall size which does not differ significantly from teeth from Bramerton.

*Mimomys reidi* Hinton 1910

(pl. 1, figs 2-4, 7; pl. 2, figs 2, 3; pl. 3, figs 4, 6-8; pl. 4, figs 4-6; pl. 5, figs 1, 9)

Material: (upper molars) 4 M1, 7 M2, 3 M3; (lower molars) 3 m1, 3 m2, 1 m3.

Measurements: M1 - 2.10 x 1.39, 2.57 x 1.53, 2.43 x 1.38, 2.50 x 1.32; M2 - 2.02 x 1.24, 1.88 x 1.18, 1.94 x 1.18, 1.88 x 1.15, 1.89 x 1.20, 2.04 x 1.24; M3 - 1.75 x 1.02, 1.89 x 1.08, 1.73 x 1.07; m1 - 2.96 x 1.25, 2.75 x 1.24; m2 - 1.85 x 1.14; m3 - 1.47 x 0.70.

Comments: These teeth represent a medium sized *Mimomys* species with relatively little crown cement, moderately high crowned teeth, and an enamel islet in m1 and M3. The triangles of m1 and M2 are incompletely closed. The M1 has a rounded lingual salient angle. The enamel is thicker on the convex parts of the triangles. Two of the M1 have three roots. One of the M2 has three roots, the rest two roots. M3 is two-rooted.

Material of this species was described by Mayhew & Stuart (1986) from a number of Early Pleistocene localities. We referred the assemblages to *Mimomys reidi* (known from its type locality, Trimingham, by only a single lower first molar). The material from Bulcamp particularly resembles that from Bramerton and Thorpe. Very similar material has been described from the Early Pleistocene of Stranzendorf, Austria, under the name *Mimomys hintoni* Fejfar by Rabeder (1981).

*Mimomys newtoni* Major 1902

(pl. 1, fig. 6; pl. 3, figs 2, 3, 5; pl. 4, figs 1-3; pl. 5, figs 3, 11, 12)

Material: (upper molars) 2 M2, 3 M3; (lower molars) 3 m1, 2 m2, 2 m3.

Measurements: M2 - 1.85 x 1.21, 1.89 x 1.26; M3 - 1.66 x 0.96; m1 - 2.74 x 1.11; m2 - 1.80 x 1.15; m3 - 1.59 x 0.90, 1.63 x 1.00.

Comments: These teeth represent a medium sized species of *Mimomys* lacking crown cement, with reverse enamel differentiation (enamel thicker on concave sides of triangles), and an enamel islet in M3. They are referred to *Mimomys newtoni* (= *M.* (*Borsodia*) *hungaricus*) (see Mayhew & Stuart 1986 for details of synonymy).

The morphology of the m1 is similar to that of the specimen from Bramerton figured by Mayhew & Stuart (1986). This is more primitive than the morphology of the type specimen of *M. newtoni* from East Runton (the crown height and the height of the enamel free areas is lower, and the *Mimomys* ridge is situated more posteriorly). Teeth with identical morphology have been figured from Stranzendorf, Austria, by Rabeder (1981) under the names *Borsodia parvisinuosa* and *B. altisinuosa*.

*Mimomys altenburgensis* Rabeder 1981

(pl. 1, fig. 1; pl. 2, fig. 1; pl. 3, fig. 1; pl. 5, figs 2, 4, 8, 10)

Material: (upper molars) 1 M1, 1 M2; (lower molars) 1 m1, 3 m2, 1 m3.

Measurements: M1 - 2.20 x 1.18; M2 - 1.84 x 1.10; m1 - 2.39 x 1.02; m2 - 1.51 x 0.92, 1.89 x 1.05; m3 - 1.58 x 0.92.

Comments: These teeth represent a small *Mimomys* species with little crown cement, confluent triangles in m1 and M2, and poorly differentiated enamel. The buccal re-entrant angles are broadly open. The teeth were recognised as representing a new species, and are referred to *Mimomys altenburgensis* described from Deutsch Altenburg, Austria, by Rabeder in 1981.

Teeth of this species have been described from Bramerton and Thorpe by Mayhew & Stuart (1986), and the Bulcamp material is very similar. The confluency of the triangles of M2 in *M. altenburgensis* is similar to that found in *M. pitymyoides* which may be descended from this species.

## DISCUSSION

### a) Comparison with other English faunas and relative age

A grouping of Early Pleistocene microtine faunas from England was developed by Mayhew & Stuart (1986) (see Table 1, p. 73). The assemblage from Bulcamp is assigned to faunal group 2 for the following reasons: *Mimomys pliocaenicus* teeth are relatively low crowned; *M. reidi* teeth are relatively low crowned; *M. newtoni* teeth are more primitive than the type from group 1 deposits at East Runton; *M. altenburgensis* is present and not its presumed descendent, *M. pitymyoides*; *M. blanci* is absent. The material from Bulcamp is very similar to that from Bramerton. Group 3 faunas are not well characterised, but *M. blanci* is present.

On the basis of the microtine fauna, the deposits at Bulcamp appear to be broadly similar in age to those at Bramerton, type locality of the Bramertonian Stage. The relationship of the Bulcamp deposits to the crags on the nearby coast at Easton Bavents and Covehithe, which underlie the type Baventian and have been correlated with the Antian, remains to be clarified. On the basis of the vertebrate faunal evidence there are no grounds to indicate that the Baventian deposits are older than Bramertonian.

The assemblage described here adds two genera, *Micromys* and *Desmana* to the vertebrates from the Bramertonian Stage. These records are a earliest for these genera from Britain.

### b) Comparison with continental European faunas and relative age

The relationship between group 2 faunas from Britain and continental Europe has been considered in detail by Mayhew and Stuart (1986). Therefore only a brief discussion is given here.

In the Netherlands, a small mammal fauna from the Early Pleistocene of Tegelen, from zone Tiglian TC5, was described in a preliminary report by Freudenthal *et al.* (1976). The fauna contains *Desmana* and *Micromys*, but differs from that of Bulcamp in the presence of *Mimomys blanci*, and absence of both *Mimomys newtoni* (see Mayhew & Stuart for synonymy of this species), and *Mimomys altenburgensis*. A full comparison awaits description of the Tegelen fauna. Provisionally I consider this fauna to be somewhat later than that from Bulcamp. A date of 1.6 million years (Ma) for the end of the Tiglian Stage was proposed by van Montfrans (1971), suggesting a date of around 1.8 Ma for the Tegelen fauna.

Arvicolid remains from Austria have been described by Rabeder (1981). The Bulcamp assemblage resembles closely those from the fissure deposits Deutsch-Altenburg 20 and 21 and those from the lower levels of the Stranzendorf loess section (SdD-SdF). A comparison of nomenclature for the species is given below:

| Taxon | Bulcamp (present paper) | | Austria (Rabeder 1981) |
|---|---|---|---|
| 1 | *M. pliocaenicus* | = | *M. praepliocaenicus* |
| 2 | *M. newtoni* | = | *B. parvisinuosa, aequisinuosa* |
| 3 | *M. reidi* | = | *M. hintoni, M.* cf. *reidi* |
| 4 | *M. altenburgensis* | = | *M. altenburgensis,*<br>*M. stranzendorfensis* |

The species *M. blanci*, which is absent from the assemblages at Bramerton and Bulcamp, is also not found in these Austrian faunas of presumed similar age. According to Rabeder (1981) the absolute age of the Austrian assemblages from Stranzendorf D may be approximately 2.5 Ma on the basis of palaeomagnetic investigations of the loess profile.

The fauna of Villany-3, Hungary, (type locality of the Villanyian Stage) includes the following *Mimomys* species: *M. pliocaenicus*, *M. pitymyoides*, *M. newtoni* (= *M. hungaricus*), *M. reidi*, *M. rex* and *M. blanci* ("*M. newtoni*") (Freudenthal *et al.* 1976, Jànossy and van der Meulen 1975). *Microtus* is not present, but occurs in the directly overlying sediments of Villany-5 (van der Meulen 1974).

*M. newtoni* from Bulcamp is more primitive than from Villany-3 or Villany-5 (lower crowned, anterior cap of m1 less developed). This indicates that the fauna from Bulcamp is older than that from Villany-3 and confirms a Villanyian or earlier age.

In summary, the Bulcamp assemblage dates from the Bramertonian Stage of the English sequence, from the Tiglian (older than TC5) of the Dutch sequence and from the Villanyian or earlier of Hungary. The absolute age is expected to lie between 1.8 and 2.5 Ma.

## CONCLUSIONS

a) A fauna of small mammals has been recovered from Early Pleistocene Norwich Crag deposits at Bulcamp Union Farm Pit. The following taxa are identified: *Densmana thermalis*, *Micromys* sp., *Mimomys pliocaenicus*, *Mimomys newtoni*, *Mimomys reidi*, *Mimomys altenburgensis*.

b) The microtine fauna resembles that of the lower shell bed at Bramerton, and the faunas from these two localities are considered to be similar in age (Bramertonian Stage).

c) The records of *Desmana* and *Micromys* are the first for the Bramertonian and the earliest for Britain.

d) The Bulcamp fauna supports the faunal division between the Norwich Crag and the basal part of the Cromer Forest Bed Formation recognised by Mayhew and Stuart (1986).

e) The fauna dates from a period earlier than that in which the Tegelen fauna (Tiglian TC5) or the Villany-3 fauna (type Villanyian) accumulated. An absolute age of between 1.8 and 2.5 Ma is indicated.

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Table 1. Microtine faunal groups in the English Lower Pleistocene (after Mayhew & Stuart 1986)

| GROUP | LOCALITY | AGE/DATING |
|---|---|---|
| Group 1 | Sidestrand<br>Overstrand<br>East Runton<br>West Runton | Pre-Pastonian |
| Group 2 | Bramerton<br>Thorpe (Norwich)<br>Bulcamp | Bramertonian and/or succeeding cool phase (≠ Pre-Pastonian) |
| Group 3 | Covehithe<br>Easton Bavents | Baventian and/or preceding warm phase |

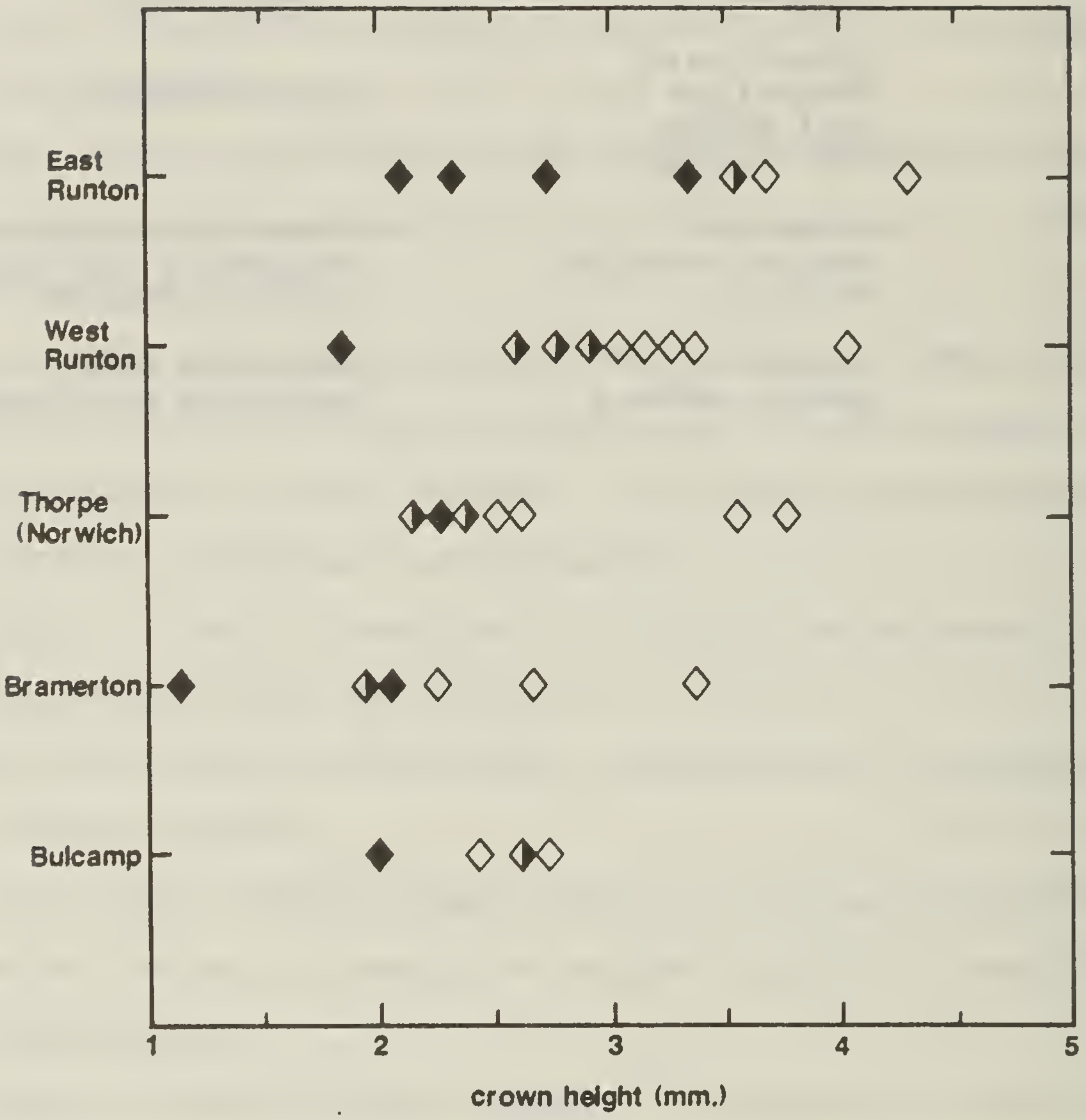


Figure 1. Presence of enamel islet in relation to crown height in lower first molars of *Mimomys pliocaenicus* from various localities. ◇ islet absent, ◆ trace of islet in dentine. The material from Bulcamp is more similar to samples from Bramerton and Thorpe.

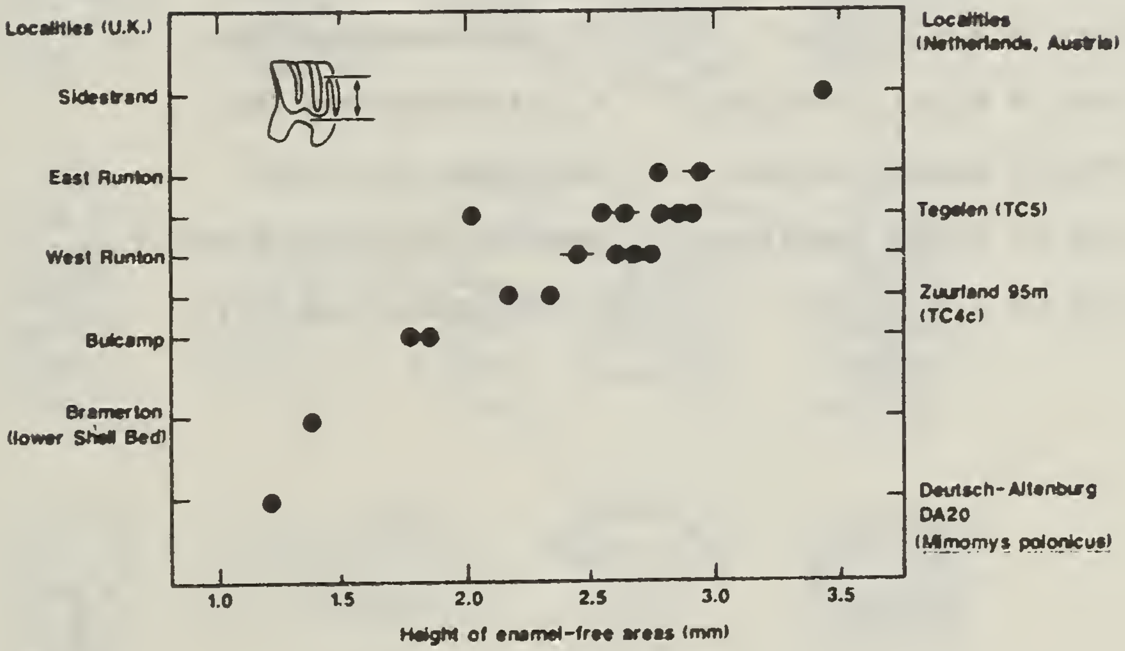
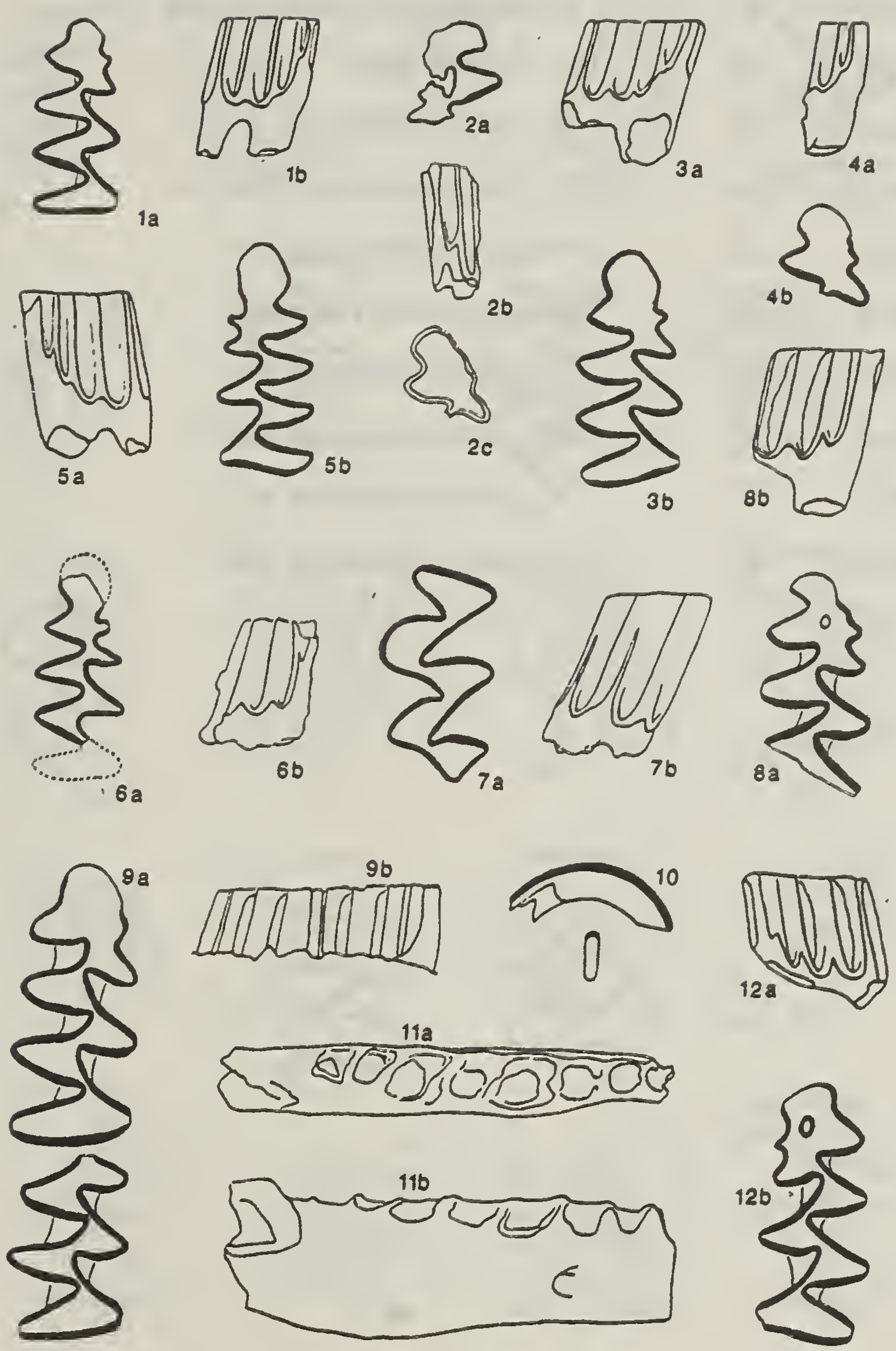


Figure 2. Height of enamel free area in upper third molars of *Mimomys pliocaenicus* from various localities. The points represent average values of buccal and lingual enamel free areas. Points with line represent teeth in which one or both enamel free zones reach the wear surface. Material from Bulcamp is intermediate between *Mimomys polonicus* from Deutsch-Altenburg (Rabeder 1981) and Tiglian TC4/5 *Mimomys pliocaenicus* (Tegelen/Boring Zuurland, own observations).

Plate 1

| | | |
|---|---|---|
| Fig. 1, a,b | m1 | *Mimomys altenburgensis* PL28 |
| Fig. 2 a,b,c | m1 | *M. reidi* PGC9 |
| Fig. 3 a,b, | m1 | *M. reidi* PL12 |
| Fig. 4 a,b | m1 | *M. reidi* PGC8 |
| Fig. 5 a,b | m1 | *M. newtoni* PGC6 |
| Fig. 6 a,b | m1 | *M. newtoni* DM9 |
| Fig. 7 a,b | M1 | *M. reidi* PGC11 |
| Fig. 8 a,b | m1 | *M. pliocaenicus* DM8 |
| Fig. 9 a,b | m1,m2 | *M. pliocaenicus* DM6 |
| Fig.10 upper incisor | | *Micromys* sp. PL23 |
| Fig.11 right mandible | | *Desmana thermalis* PGC17 |
| Fig.12 a,b | m1 | *M. pliocaenicus* PL13 |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12b

Plate 2

| | | |
|---|---|---|
| Fig. 1 a,b | M1 | *Mimomys altenburgensis* PL5 |
| Fig. 2 a,b,c | M1 | *M. reidi* DM5 |
| Fig. 3 a,b | M1 | *M. reidi* PGC12 |
| Fig. 4 a,b | M1 | *M. pliocaenicus* PL4 |
| Fig. 5 a,b | M1 | *M. pliocaenicus* DM2 |
| Fig. 6 a,b | M1 | *M. pliocaenicus* DM3 |
| Fig. 7 a,b | M1 | *M. pliocaenicus* PL3 |
| Fig. 8 a,b | M1 | *M. pliocaenicus* PGC10 |
| Fig. 9 a,b | M1 | *M. pliocaenicus* PL1 |
| Fig.10 a,b | M1 | *M. pliocaenicus* DM4 |

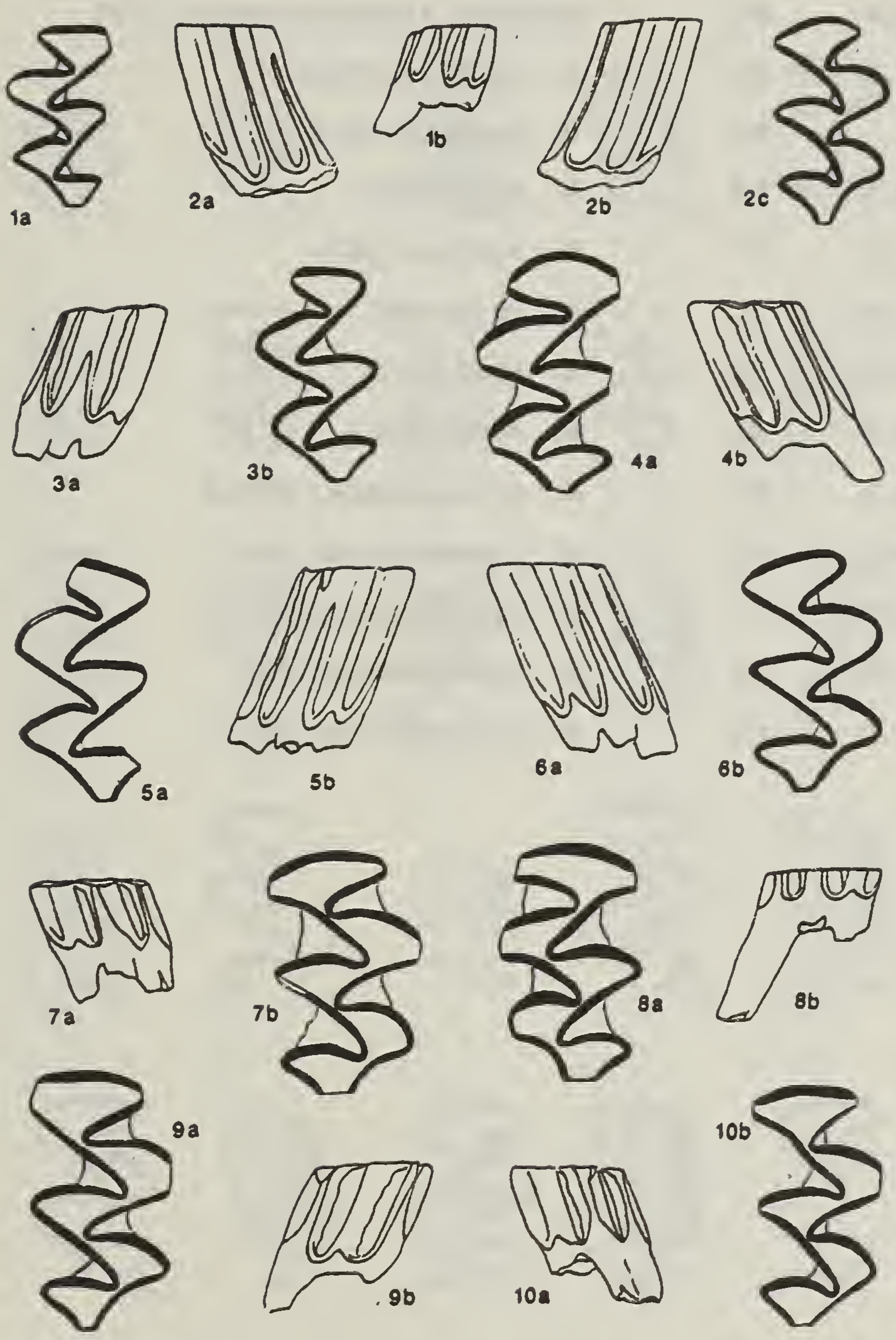
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Plate 3

| | | |
|---|---|---|
| Fig. 1 a,b | M2 | *Mimomys altenburgensis* PL35 |
| Fig. 2 a,b | M2 | *M. newtoni* PGC18 |
| Fig. 3 | M2 | *M. newtoni* DM16 |
| Fig. 4 a,b | M2 | *M. reidi* PL6 |
| Fig. 5 a,b | M2 | *M. newtoni* DM21 |
| Fig. 6 a,b | | *M. reidi* DM7 |
| Fig. 7 a,b | M2 | *M. reidi* PL9 |
| Fig. 8 a,b | M2 | *M. reidi* DM12 |
| Fig. 9 a,b | M2 | *M. pliocaenicus* PGC14 |
| Fig.10 a,b | M2 | *M. pliocaenicus* PL8 |
| Fig.11 a,b | M2 | *M. pliocaenicus* PGC13 |
| Fig.12 a,b | M2 | *M. pliocaenicus* PL7 |
| Fig.13 a,b | M2 | *M. pliocaenicus* PL33 |

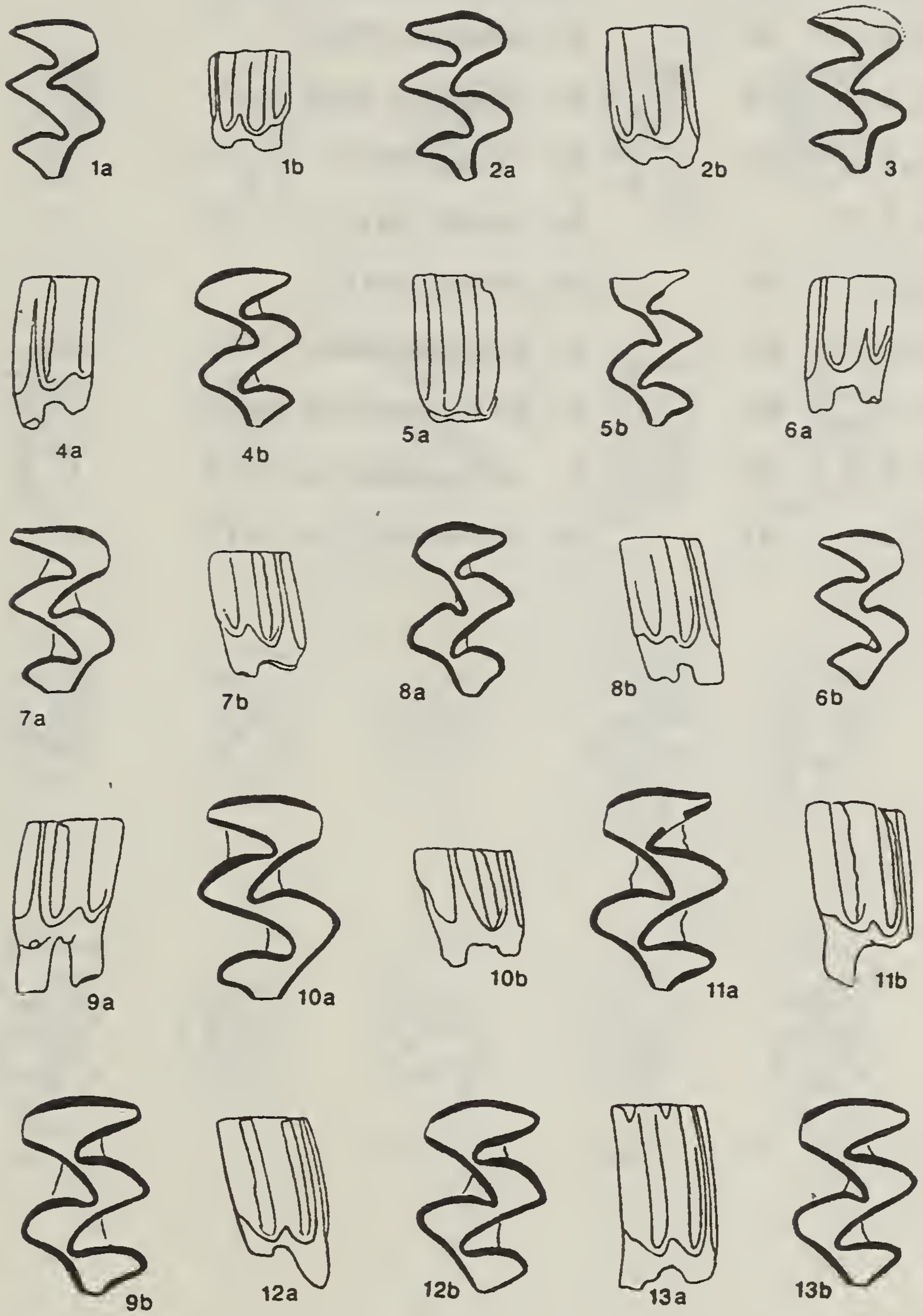
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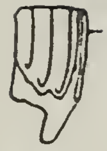
Plate 4

| | | |
|---|---|---|
| Fig. 1 a,b | M3 | *Mimomys newtoni* DM18 |
| Fig. 2 a,b | M3 | *M. newtoni* PL25 |
| Fig. 3 a,b | M3 | *M. newtoni* DM14 |
| Fig. 4 a,b | M3 | *M. reidi* DM15 |
| Fig. 5 a,b | | *M. reidi* DM13 |
| Fig. 6 a,b | M3 | *M. reidi* PL15 |
| Fig. 7 a,b | M3 | *M. pliocaenicus* PL27 |
| Fig. 8 a,b | M3 | *M. pliocaenicus* PL17 |
| Fig. 9 a,b | M3 | *M. pliocaenicus* PL24 |
| Fig.10 a,b | M3 | *M. pliocaenicus* PL16 |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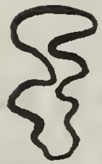
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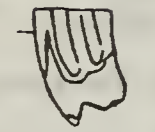
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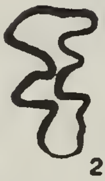
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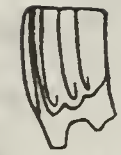
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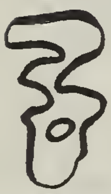
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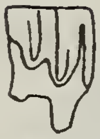
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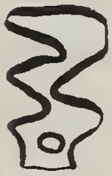
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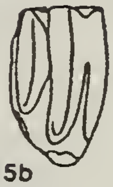
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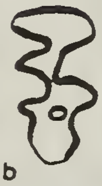
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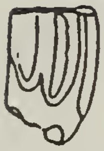
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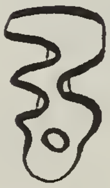
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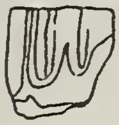
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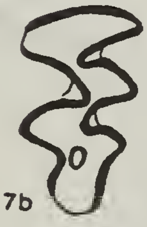
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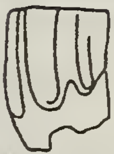
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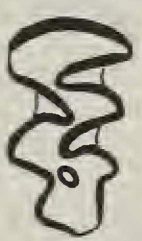
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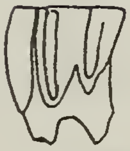
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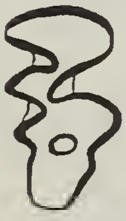
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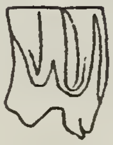
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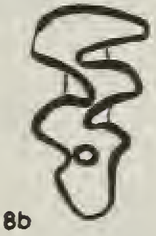
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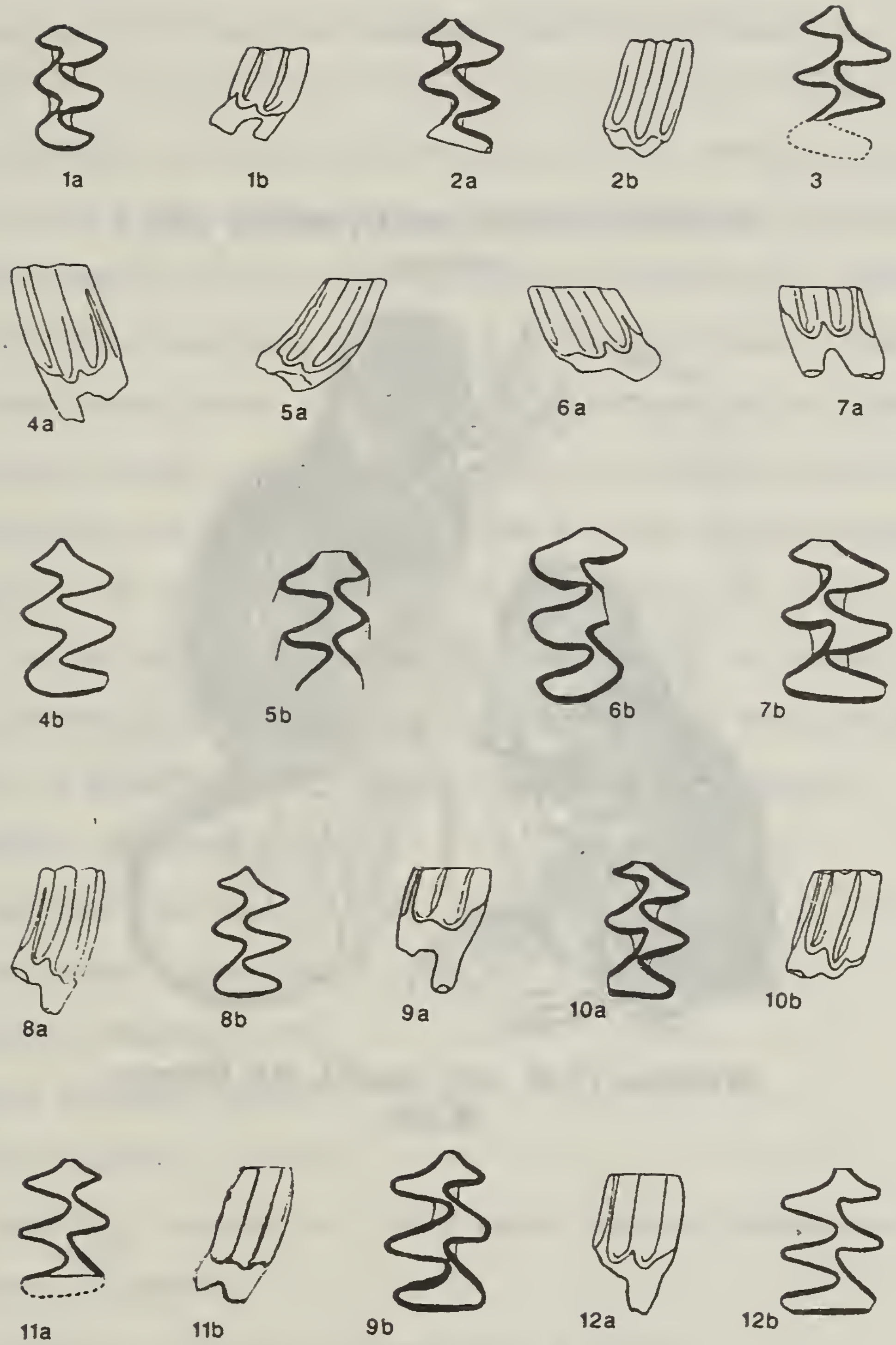
Plate 5

| | | |
|---|---|---|
| Fig. 1 a,b | m3 | *Mimomys reidi* PGC4 |
| Fig. 2 a,b | m2 | *M. altenburgensis* DM22 |
| Fig. 3 | m2 | *M. newtoni* PL10 |
| Fig. 4 a,b | m2 | *M. altenburgensis* PGC27 |
| Fig. 5 a,b | m3 | *M. pliocaenicus* PL29 |
| Fig. 6 a,b | m3 | *M. pliocaenicus* PGC3 |
| Fig. 7 a,b | m2 | *M. pliocaenicus* PGC2 |
| Fig. 8 a,b | m3 | *M. altenburgensis* PGC24 |
| Fig. 9 a,b | m2 | *M. reidi* PGC18 |
| Fig.10 a,b | m2 | *M. altenburgensis* PL11 |
| Fig.11 a,b | m3 | *M. newtoni* DM20 |
| Fig.12 a,b | m2 | *M. newtoni* PGC1 |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12b

MICRŎMYS.—(Gr. *μικρός*, small; *μῦς*, a mouse.)

Minūtus (Lat. *very small*), *the Harvest Mouse.*

(from "The Boy's Own Natural History", undated, Routledge, p. 77.)

Bull. geol. Soc. Norfolk, 39, 87-90 October 1990

# A NEW SPECIMEN OF THE OTTER *ENHYDRA REEVEI* (NEWTON, 1890) FROM THE CRAG OF BRAMERTON, NORFOLK

Gerard F. Willemsen

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## INTRODUCTION

Newton (1890, 1891) described a new otter species, *Lutra reevei*, based on a right $M_1$ found by Mr James Reeve at Bramerton. The specimen was stored in the Norwich Castle Museum (nr. 548). During many years, this specimen was the only specimen, known of this species. But some years ago, Mr Philip Cambridge found a second specimen, also a right $M_1$, at Bramerton. He kindly put the specimen at my disposal for study. The specimen is now in the Sedgwick Museum (Cambridge). In this paper, some remarks are made on the new specimen. A detailed description as well as a more detailed discussion of the taxonomy and the phylogenetical relationships of the species will be published elsewhere (Willemsen, in prep.).

## DESCRIPTION AND TAXONOMY

Family Mustelidae Swainson, 1835

Subfamily Lutrinae Baird, 1857

Tribe Enhydrini Sokolov, 1973

Genus *Enhydra* Fleming, 1822

*Enhydra reevei* (Newton, 1890)

Holotype: Right $M_1$, stored in the Norwich Castle Museum no. 548

Type locality: Bramerton

Material: Right $M_1$, Sedgwick Museum nr. X.17989

The specimen is worn very much by use: the crown is completely worn away and only the basis of it is present. This contrasts with the holotype, which consists of a crown, which is completely unworn

(Newton, 1890, 1891). The tooth is two-rooted, but the posterior root is broken off. The tooth is very broad. Its length is 13.5 mm, its width 10.2 mm. There is a strong bilateral symmetry. The sides are almost parallel. The arrangement of the cuspids and the shape of the tooth are essentially the same as in the holotype.

The species was originally described as a *Lutra* Brisson, 1762 by Newton (1890, 1891). Pohle (1919) transferred it to the genus *Latax* Gloger, 1827, which is a junior synonym of *Enhydra* Fleming, 1822. Kurten (1968) transferred it to the genus *Aonyx* Lesson, 1827. He was followed by many later authors. There are however many differences with *Aonyx* and related forms in the morphology of the lower carnassial, as will be shown in Willemsen (in prep.). Repenning (1976) assigned the species to the extinct genus *Enhydriodon* Falconer, 1868. Contrary to him, I think that a phylogenetical relationship with *Enhydra* is more probable than with European Miocene *Enhydriodon*, though *E. reevei* cannot be considered to be ancestral to the extant Sea Otter *E. lutris*, as Pohle (1919) supposed (Willemsen, in prep.).

## STRATIGRAPHY

The second specimen of *E. reevei* is particularly welcome because its exact stratigraphical position is known. This is not the case with the holotype, for which we can't even be certain in which of the two pits at Bramerton it was found. The new specimen was found in the Upper Shell Bed in Blake's Pit (Cambridge, pers. comm.). The USB lies on top of the type Bramertonian and it probably represents a cool phase following the temperate Bramertonian (see Funnell et al., 1979; Mayhew and Stuart, 1986). A pollen sample from the USB showed a *Pinus*-Ericales-Graminea association (Funnell et al., 1979). The mollusc fauna from the USB contains northern elements and point to an estuarine environment (Cambridge, 1979). *E. reevei* was probably a coastal species, and well at home in estuaries. Its way of life may have resembled the present Sea Otter (*E. lutris*), which lives on the northern Pacific coast.

## ACKNOWLEDGEMENT

I would like to express my sincere thanks to Mr Philip Cambridge, who allowed me to study the specimen and gave me valuable information on the Bramerton locality.

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Bull. geol. Soc. Norfolk, 39, 91-96 October 1990

# OTOLITHS AND OTHER FAUNA FROM THE CRAG OF BULCAMP, SUFFOLK

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258 Bluebell Road, Norwich NR4 7LW

## INTRODUCTION

Preceding papers in this Bulletin (Long 1990, Lord 1990, Preece 1990, Mayhew 1990, Willemsen 1990) record the occurrence and interpretation of the different faunal groups obtained from the Bulcamp excavations of 1979 (Cambridge 1982) and related deposits. In this paper are recorded the occurrence of otoliths and a listing of other fossil remains including rarer species of molluscs not included in the quantitative records of Funnell (1983) and Long (1990).

## OTOLITHS

Fish otoliths ("earbones") from the Crags have not been re-studied since Newton (1891) illustrated certain forms, except for the occurrence of a single species identified as *Agonus cataphractus* (Linné) and obtained from the topmost shell bed at Blake's Pit, Bramerton (Stinton 1985). (Note: the locality for *A. cataphractus* is correctly shown in the Plate description, but erroneously given as Chillesford in the Distribution Table and as "from the Chillesford Gravels" on page 215 by Stinton.)

Otoliths are not abundant in Crag deposits and large amounts of material usually need to be sorted in order to obtain small numbers of otoliths. Some Norwich Crag sites are richer than others. So far otolith faunas from different localities have not shown any notable differences, but it should be emphasised that numbers obtained have been small.

Dr P.A.M. Gaemers of the Rijksmuseum van Geologie, Leiden, The Netherlands has kindly identified and provided an illustration (Fig.

Cambridge

1) of a specimen of *Elginus parallelus* (Gaemers) from Bulcamp. This is also the commonest otolith at Easton Bavents and Covehithe Warren, although previously only known from the Pliocene of Belgium. These and other species and specimens collected by the present author and Dr P.E. Long have been studied by Dr Gaemers as part of his continuing studies on the Pliocene and Early Pleistocene otoliths of the Crags. The full list of otolith species obtained from Bulcamp is as follows: 8 x *Elginus parallelus* (Gaemers); 1 x *Merlangius pseudaeglefinus* (Newton); 1 x *Melanogrammus aeglefinus* - haddock; 2 x *Pleuronectes platessa* (Linné) - plaice; 1 x *Gadus morhua* Linné - cod; 3 x *Gadinarum* sp.; 1 x *Myoxocephalus* sp.; 1 x *Ammodytidarus* sp.

OTHER FAUNA

The following list of fauna obtained from Bulcamp includes a number of species* which occur too infrequently to appear in previous quantitative or semi-quantitative listings (Funnell 1983, Long 1990). It also includes a number of taxa$^+$ not recorded in previous papers on the Bulcamp collections of 1979-80.

Bivalves

**Acila cobboldiae* (J. Sowerby) G 2571.C.1;

*Arctica islandica* (Linné) G 1853.B.1;

**Astarte (Nicania) montagui* (Dillwyn) G 1854.J.14;

*Cerastoderma edule*;

**C. edule ?glaucum*;

**Corbula gibba*;

**Divaricella divaricata* (Linné) G 2410.D.5;

**Ensis* sp. G 8191.S;

**Hiatella gallicana* (Lamarck) G 1895.C.5;

**Lima*;

**Lucinoma borealis* (Linné) G 1839.E.14;

*Macoma calcarea* (Gmelin) G 1838.F.20;

*M. obliqua* (J. Sowerby) G 1081.G.40;

*M. praetenuis* (Leathes) G 1439.G.40;

**Mactra ?corallina* (Linné) G 2593.A.5;

**Modiolus* sp.;

**Mya truncata* Linné G 1850.D.5;

*Mytilus edulis* Linné G 1196.F.5;

*Nucula* sp. G 8263.5;

*Scrobicularia plana* Da Costa G 1074.D.2;

**Spisula ovalis*?;

*Spisula subtruncata* (Da Costa);

**Venus fasciata* Da Costa;

*Yoldia myalis*.Couthouy G 1900.F.

**Gastropods**

**Actaeon tornatilis* (Linné) G 1846.B.14;

*Amauropsis islandica* (Gmelin) G 649.F.7;

**Barnea* sp.;

*Boreoscala groenlandicum* Perry G 1841.E.7;

*Buccinum undatum* Linné G 8264.5;

**Calyptraea chinensis* (Linné) G 1449.B.7;

*Ellobium pyramidale* (J. Sowerby) G 1466.E.6;

**Epitonium clathratulum* (Kanmacker);

**Gibbula tumida* (Montague) G 1072.A.12;

**Hinia incrassata* (Ström);

*Hydrobia* spp.;

*Littorina littorea* Linné G 1832.K.7;

**Littorina rudis/saxatilus*;

Cambridge

*"*Nassa*" *pusillinus* Wood;

*Natica (Euspira) catena* (Da Costa) G 2411.A.8;

*Nucella lapillus* (Linné) G 1896.L.20;

**Oenopta turricula* (Montague);

?*Oenopta* sp.;

*Potamides icenicus* Harmer G 1834.D.40;

*Retusa alba* (Kanmacker) = *R. obtusa* Montague G 1898.D.14;

**Ringicula ventricosa* (J. Sowerby) G 1892.D.22;

**Turbonilla internodula* (Wood);

**Turritella communis* Risso G 1071.B.3;

**T. incrassata* (J. Sowerby) - derived from Red Crag G 1070.C.4;

Sponges

+*Cliona* sp. - borings in shell G 1853.B.5;

Corals

+*Balanophyllia calyculus* S. Wood-derived from Red Crag G 1441.A.2;

Barnacles

+*Balanus* spp.

Fish

vertebrae G 1836.E.22;

+"*Platax*" *woodwardi* Agaziz G 1435.H.9;

+*Raia* sp. - dermal tubercle G 5267.A.1;

Mammals

proximal end of ?cervid scapula G 8262.1;

pieces of elephant ivory;

carnassial tooth and lower jaw, probably of the otter "*Lutra*" *reevei* (see Willemsen 1990).

Note that the few, small, mostly worn fragments of bryozoans, corals (*Sphenotrochus* and *Balanophyllia caliculus*) and *Turritella incrassata*, complement the relict foraminifers (Funnell 1983) and could be derived either directly from the Coralline Crag or from the Red Crag. The amount of this derived material is however relatively insignificant.

Note: Numbered specimens, (in list above), together with other materials from Bulcamp, have been donated to the Sedgwick Museum, Cambridge.

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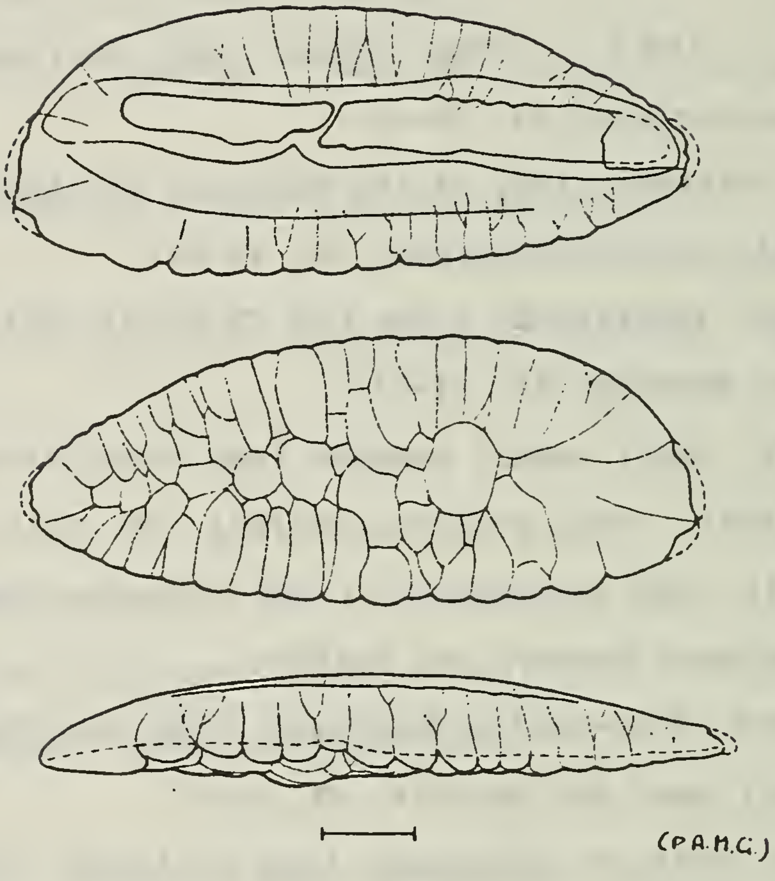

Fig. 1. Inner and outer surfaces and ventral view of the sagitta of *Elginus parallelus* (Gaemers 1976). Covehithe Warren, Unit "D", collection P.E. Long.

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The Geological Society of Norfolk exists to promote the study and knowledge of geology, particularly in East Anglia, and hold monthly meetings throughout the year.

Visitors are welcome to attend the meetings and may apply for membership of the Society. For further details write to the Secretary, Geological Society of Norfolk, Castle Museum, Norwich NR1 3JU.

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Copies of the Bulletin may be obtained from the Secretary at the address given above; it is issued free to members.

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The illustration on the front cover is taken from Figure 286 of Lyell's "Elements of Geology", 1865 (6th Edition), and shows columns of potstones in the Late Campanian Chalk of a quarry on the River Bure near Horstead, Norfolk. The upper part of the section consists of Crag gravels resting on an erosion surface which truncates the potstone columns.

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# BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

(FOR ARTICLES ON THE GEOLOGY OF EAST ANGLIA)

No 40 for 1990

CONTENTS INCLUDE:

Campanian and Maastrichtian
Chalk of Norfolk

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of the Southern North Sea

Quaternary deposits
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## EDITORIAL

This is the last Bulletin to be produced by the above team, so the first point to make is that the next Bulletin will be produced by the new team, as below. Please send your contributions to them and not to us:

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We are still rather behind schedule with Bulletin No. 40, which should have appeared in 1990, but we hope the mixture of Chalk, Crag and Glacial topics contains something for everyone.

We wish our successors well with future issues.

## Editorial

### INSTRUCTIONS TO AUTHORS

Potential contributors should note that although we prefer manuscripts to be submitted as word-processor print-out or typewritten copy we will gladly accept neatly handwritten material. We nevertheless also gratefully accept the submission of disks, in addition to hard copy of word-processed manuscripts. As we can translate from most word-processing programmes this saves considerable re-typing time.

It is important that the style of the paper, in terms of capitalisation, underlining, punctuation, etc. is made to conform as strictly as possible to those recently used in the Bulletin. All measurements should be given in metric units. The reference list is the author's responsibility and should always be carefully checked.

Illustrations are important. They should be drawn with thin dense black ink lines. Thick lines, close stipple or patches of solid black should be avoided as these tend to spread in the printing process employed. Original illustrations should, before, reproduction, be not more than 175 mm by 225 mm. Full use should be made of the first (horizontal) dimension, which corresponds to the width of print on the page, but the second (vertical) dimension is an upper limit only. Half-tone (photographic) plates can also be accepted, provided the originals exhibit adequate contrast, and when their use is warranted by the subject matter.

Authors are reminded that the Bulletin of the Geological Society of Norfolk exists to publish research papers, notes or general articles relevant to the geology of East Anglia as a whole, and does not restrict consideration to articles covering Norfolk alone.

Bull. geol. Soc. Norfolk, 40, 3-24 July 1991

# A SUMMARY OF THE STRATIGRAPHY OF CURRENT EXPOSURES OF *BELEMNITELLA MUCRONATA* ZONE CHALK (CAMPANIAN, UPPER CRETACEOUS) IN NORFOLK

Andrew J. Pitchford

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## ABSTRACT

The stratigraphy of current exposures of chalk of the *Belemnitella mucronata* Zone (Campanian, Upper Cretaceous) in Norfolk is reviewed. The stratigraphical levels of the boundaries of the four sub-divisions of the zone after Wood (1988) [Pre-Weybourne Chalk, Weybourne Chalk, Beeston Chalk, and Paramoudra Chalk] are considered. Faunal summaries are given together with brief descriptions of extant sections.

## INTRODUCTION

This paper records the stratigraphy of all current (1989) exposures of chalk of *Belemnitella mucronata* Zone age in Norfolk (Figure 1) visited by the author during fieldwork for the Ph.D. thesis (Pitchford, 1989) upon which this paper is based.

A log for each section was produced by measuring the vertical spacing between recognisable flint bands, which occur in all but a few of the smallest exposures. The shape, size, form, colour, and thickness of cortices (skins on the surfaces of flints) were all carefully noted. Characteristic flints in each band were sketched and redrawn at a 1:50 scale when sections were drafted. A "representative" 5m wide section of chalk was drawn for each locality. Each drawn flint band was, as far as possible, an accurate representation of the equivalent band visible in the chalk face. The colour and nature of the chalk and the presence of hard/soft bands was noted.

Most flints fall into one of four shape categories, which grade into each-other. The two end-member forms are "nodular" (irregularly shaped flints with numerous protuberances) and "tabular" (regular flints with smooth upper and lower faces). Two intermediate shape forms "semi-nodular" and "semi-tabular" are recognisable. Two other terms were used to describe specifically shaped flints; "sheet" for laterally continuous (up to 5m) tabular flints, and "spindle" for small "rod-like" flints. In places, particularly in the Paramoudra Chalk Division of the *mucronata* zone (q.v.) very large barrel shaped flints (paramoudras) are common.

About 2,700 macrofossils were collected from sections and a varied "mesofauna" (fragments of larger fossils and small faunal elements [<4mm]) was sieved from 250 chalk bulk samples obtained from exposures and boreholes. Complete faunal lists are given elsewhere (Pitchford, 1989) and only common fossils and species with stratigraphic significance will be considered herein.

For a list of former *mucronata* chalk exposures that have been obliterated or are currently obscured see Appendix 1.

The zonal boundaries are uncertain since neither is exposed, although the lower may have been present in old sections (where chalk was not visible in 1987) at Bawburgh (TG 1635 0894) and lies between Ringland (TG 1300 1460) and Taverham Park (TG 1474 1386) (Wood, 1988, pp. 11, 22-3). The upper boundary is nowhere

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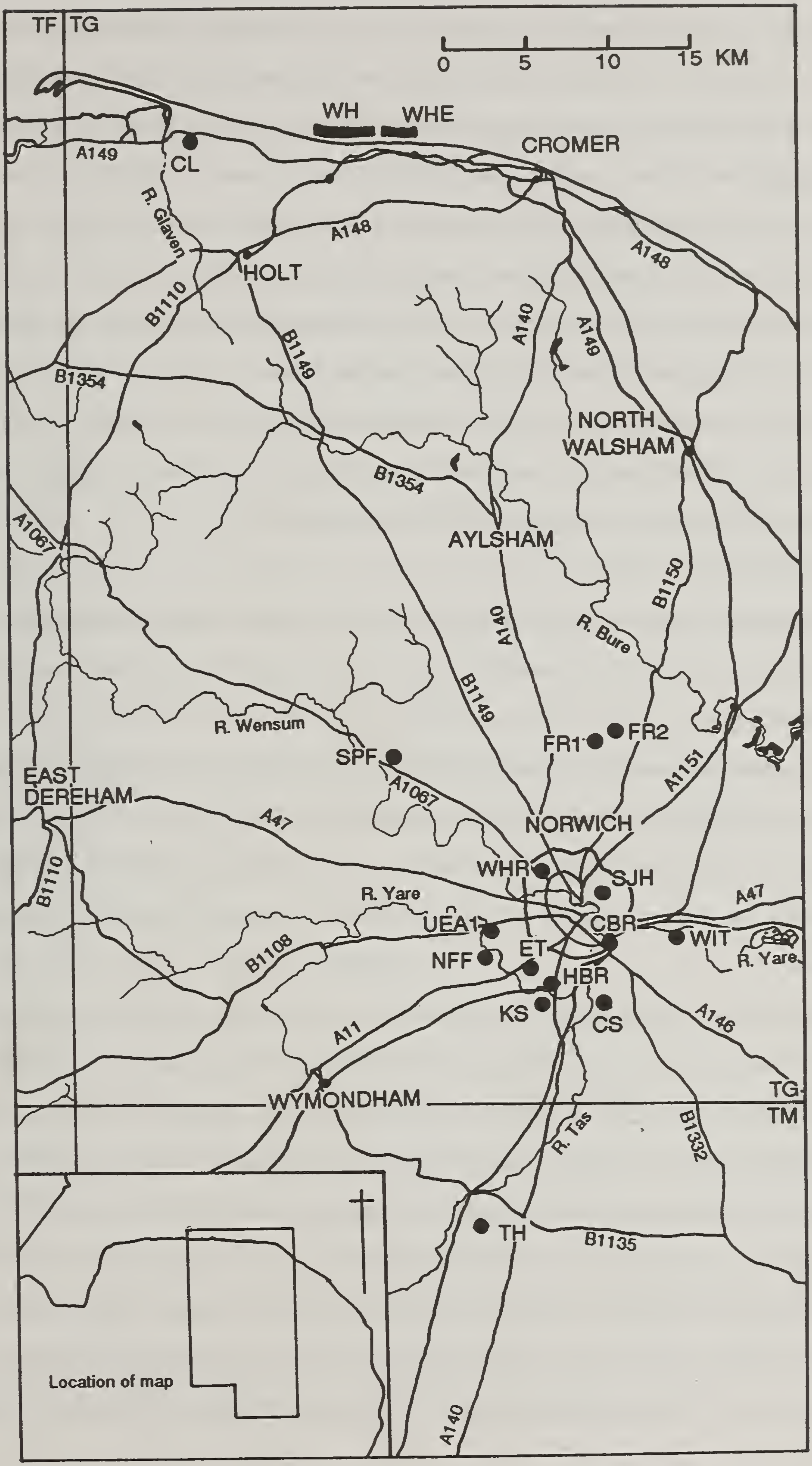
FIGURE 1 Approximate geographical locations of sections described in this paper. Grid lines represent 100km National Grid Lines. Abbreviations: CBR=Colmans, Bracondale; CL=Cley-next-the-Sea; CS=Caistor St. Edmund; ET=Eaton; FR1=Frettenham (JSS. Aggregates); FR2=Frettenham (WM. Howes); HBR=Harford Bridges; KS=Keswick; NFF=Newfound Farm, Cringleford; SJH=St. James Hollow; SPF=Spring Farm, Attlebridge; TH=Tharston; UEA1=University of East Anglia; WH=Weybourne Hope-Old Butts Gap; WHE=Weybourne Hope East; WHR=Whiffler Road, Hellesdon; WIT=Whitlingham.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B1354
NORTH
WALSHAM
B1354
A1067
AYLSHAM
B1150
A140
R. Bure
B1149
R. Wensum
FR1
FR2
SPF
A1151
EAST
DEREHAM
A1067
A47
NORWICH
B1110
WHR
SJH
R. Yare
A47
UEA1
CBR
WIT
NFF
ET
R. Yare
B1108
HBR
KS
CS
A146
A11
WYMONDHAM
TG
TM
R. Tas
B1332
TH
B1135
Location of map
A140

exposed (the easterly dip of the chalk having taken its surface below ordnance datum level east of Cromer). Chalk of definite Maastrichtian age has been identified in glacially transported erratics on the north Norfolk coast and inland in mostly temporary exposures (Peake and Hancock, 1961, pp. 324-30; Whittlesea personal communication 1989). Maastrichtian chalk has been recognised on faunal and lithological grounds in borehole samples obtained from Wroxham (Whittlesea, 1991). The *mucronata* Zone has been divided using various criteria (see Wood, 1988, pp. 18-39 for a resumé of research history). In this paper Wood's subdivisions of the zone will be followed.

## PRE-WEYBOURNE CHALK

Exposures logged at: Spring Farm, Attlebridge; Cley-next-the-Sea; Tharston; University of East Anglia; Newfound Farm, Cringleford.

The topmost beds of the Pre-Weybourne Chalk are also exposed at Eaton Tunnels, Keswick, and Weybourne, along with the overlying Weybourne Chalk, but for ease of description they will be considered in the part of this paper dealing with the Weybourne Chalk.

*Lower*: The position of the base of the Pre-Weybourne Chalk is not clear as no chalk at the relevant horizon is currently exposed in Norfolk. Brydone (1932, p. 118) placed the boundary at the level of a change from soft yellow chalk (*Gonioteuthis* Zone) to whiter, more massive chalk above (*mucronata* Zone) which he observed in a section at Deighton Hills (TG 1490 1560) near Attlebridge. Wood (1988, pp. 13-4) believed this chalk to be part of a "raft" (i.e. not *in situ*) and possibly much higher in the succession. The boundary must lie close above the chalk formerly exposed at Ringland (TG 1340 1314) which yielded fauna indicative of youngest *Gonioteuthis* age (Wood, 1988, p. 16).

*Upper*: The upper boundary of the Pre-Weybourne Chalk has been placed at different levels by various workers. Peake and Hancock (1970, p. 339E) placed the top of their "Eaton Chalk" (equivalent to the top of the Pre-Weybourne Chalk) at the level of flint band Z of their coastal stratotype (Peake and Hancock, 1961, Figure 5). Wood (1988, p. 33) considered that it should be placed at the top of the local range of *Echinocorys* ex gr. *conica* several metres above Z and at about the level of flint band X of the stratotype. During the course of the research upon which this paper is based correlation was recognised on faunal and lithological grounds between the coastal section at Weybourne and inland localities at Keswick and Eaton. This correlation (reported elsewhere; Pitchford, 1991b) enables the upper boundary of the Pre-Weybourne Chalk to be placed at the level of the hardground usually present 25cm below flint band X of the stratotype (equivalent to flint band 3 of the Weybourne log in this paper (Figure 3)).

## PRE-WEYBOURNE CHALK FAUNAL SUMMARY

Involute spindle-shaped colonies of *Volviflustrellaria taverensis* (Brydone) and specimens of *Echinocorys* ex gr. *conica* were the only fossils obtained solely from the Pre-Weybourne Chalk. Faunal elements common throughout the division include *Belemnitella*, the brachiopods *Isocrania costata* (Sowerby) and *Cretirhynchia* spp., the bivalves *Inoceramus* spp., and *Ostrea* spp., serpulids including *Glomerula gordialis* (Schlotheim), *G. g.* var. *ilium* (Goldfuss), and *Pentaditrupa subtorquata* (Münster), and the sponges *Porosphaera globularis* (Phillips) and *P. sessilis*

Brydone. Echinoderms often found include spines of cidarid echinoids, test fragments of *Echinocorys* spp., ossicles of the asteroids *Astropecten* sp., *Metopaster* sp., and *Recurvaster* sp., and plates of the ophiuroid *Ophiura hagenowi* Rasmussen.

Bryozoans common throughout the Pre-Weybourne Chalk, include "*Biflustra*" *argus* d'Orbigny, "*Membranipora*" *flabelliformis* (d'Orbigny), *Onychocella inelegans* Lonsdale, *O. matrona* (Von Hagenow), *Woodipora disparilis* (d'Orbigny), *Clypeina rosula* (Von Hagenow), *Pustulopora* spp., and *Meliceritites* spp.

## BRIEF DESCRIPTIONS OF EXTANT SECTIONS

(See Figure 9 for relative stratigraphic positions of sections.)

### SPRING FARM (ATTLEBRIDGE) (TG 1550 1600)

Old pit in field 200m south-east of the farm buildings. 1m of very soft white chalk in pit bottom.

### CLEY-NEXT-THE-SEA (TG 0540 4400)

Carpark east of the village on the south side of the A149. Small exposure of soft yellow/brown chalk in rim of old quarry.

### THARSTON (FURZE HILL) (TM 1940 9560)

In wooded area south of the Tharston-Tasburgh road. 60cm of very soft weathered yellow chalk in centre of the old workings.

### UNIVERSITY OF EAST ANGLIA (UEA 1) (TG 1870 0840) [Figure 2]

Small faces behind groundsman's hut on University playing fields. 2.5m of soft yellow chalk in two small faces containing two bands of large black/grey nodular flints. Involute spindle-shaped colonies of *Volviflustrellaria taverensis* obtained from this section.

### NEWFOUND FARM CRINGLEFORD (TG 1892 0692) [Figure 2]

Overgrown pit west of track to University Broad from Colney Lane. 4.35m of soft white chalk with three bands of black nodular/spindle-like flints. Intense cryoturbation above top flint band.

## WEYBOURNE CHALK

Exposures logged at: Weybourne Hope-Old Butts Gap; Eaton; Keswick; Whiffler Road, Norwich; Harford Bridges; Weybourne Hope East.

### BOUNDARIES

*Lower*: Immediately above the hardground (commonly represented by

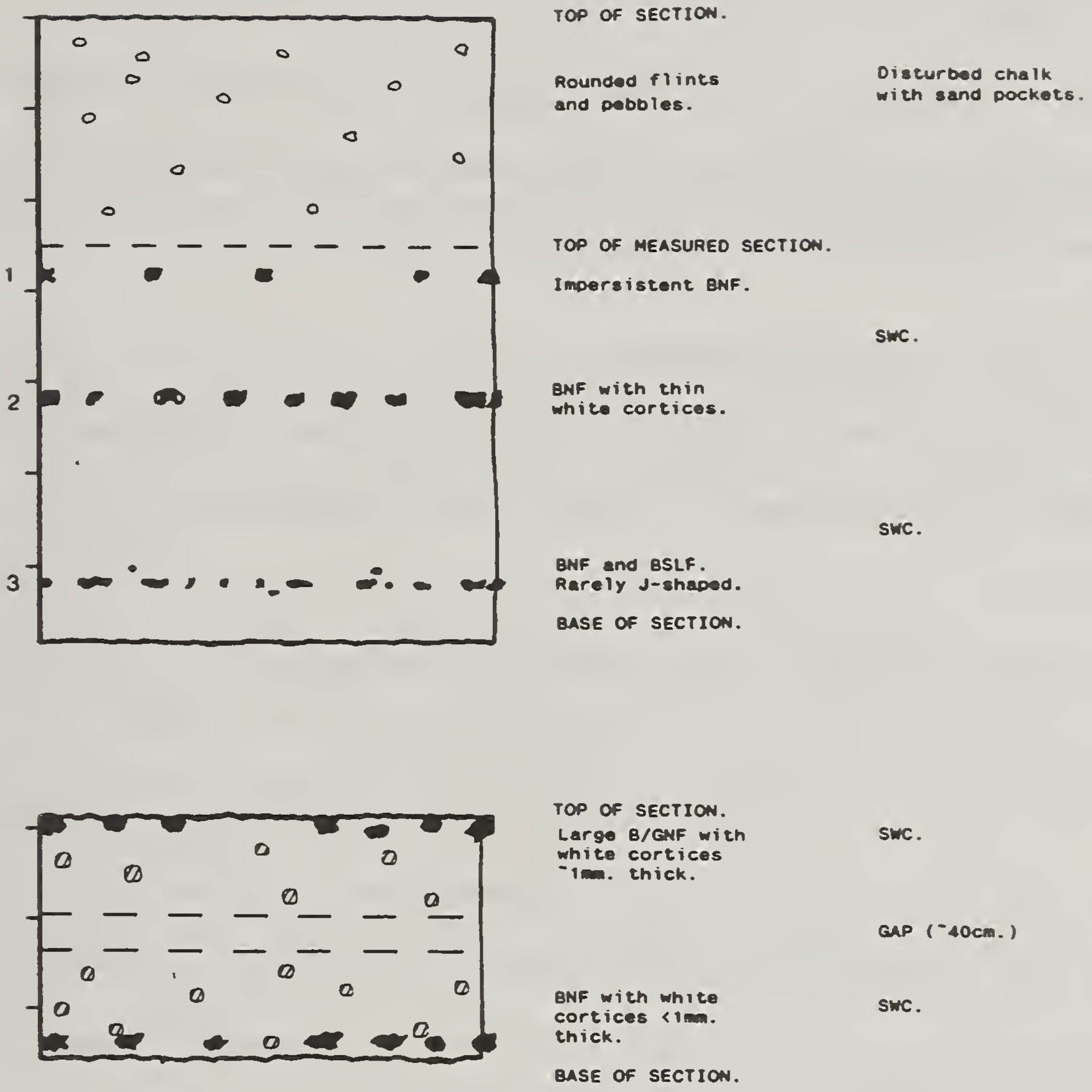
TOP OF SECTION.
Rounded flints and pebbles.
Disturbed chalk with sand pockets.
TOP OF MEASURED SECTION.
1
Impersistent BNF.
SWC.
2
BNF with thin white cortices.
SWC.
3
BNF and BSLF. Rarely J-shaped.
BASE OF SECTION.
TOP OF SECTION.
Large B/GNF with white cortices ~1mm. thick.
SWC.
GAP (~40cm.)
BNF with white cortices <1mm. thick.
SWC.
BASE OF SECTION.

FIGURE 2 Diagrammatic five-metre wide sections of the chalk at University of East Anglia (UEA 1) (TG 1870 0840) (lower figure) and Newfound Farm, Cringleford (TG 1892 0692) (upper figure) [After Pitchford, 1989 Figure 1.4]. Scale bars on left side in metres. Numbers on left-hand side indicate flint band notation used in the text. Flints are solid black (except where carious). SWC=soft white chalk; HNC=hard nodular chalk; B/W/O/YC=brown/white/orange/yellow chalk; BNF=black nodular flints; GNF=grey nodular flints; BSNF=black semi-nodular flints; BSTF=black semi-tabular flints; BTF=black tabular flints; BSLF=black spindle-like flints; BSF=black sheet flints.

hard nodular chalk) developed 25cm below the prominent flint band (band X of Peake and Hancock, 1961, Figure 5.; i.e. equivalent to band 3 of the Weybourne section published in this paper) that crops out in the cliff approximately 500m east of the carpark at Weybourne Hope.

*Upper*: The hardground of the Main Catton Sponge Bed as defined by Wood (1988, p. 62) that crops out on the foreshore underneath Sheringham life-boat station.

## WEYBOURNE CHALK FAUNAL SUMMARY

The hardground complex with its rich suite of oysters (including *Ostrea* spp., *Pycnodonte vesiculare* (Lamarck), and *Hyotissa semiplana* (J. de C. Sowerby)), in the middle of the division, allows it to be split into three (Weybourne 1,2 and 3 of Wood, 1988, pp. 34-5), since the chalk above and below the complex rarely contains oysters. Other fossils common throughout the Weybourne Chalk include the rhynchonellid *Cretirhynchia* spp. (mostly *C. ?norvicensis* (juv.) Pettitt), *Belemnitella*, *Echinocorys* spp., *Micraster stolleyi* (Lamarck) and *M. glyphus* Schleuter (which both die out at the top of the division).

Mesofaunal elements commonly encountered in bulk samples include fragments of the long ranging brachiopods *Magas* spp. and *Terebratulina* spp., and the bivalve *Inoceramus* spp. The serpulid *Glomerula gordialis*, asteroid ossicles, spines of cidarid echinoids, and plates of the ophiuroids *Ophiomusium granulosum* (Roemer) and *Ophiura* sp. are regularly collected. Amongst the bryozoans, long ranging forms of "*Biflustra*" *argus*, "*Membranipora*" spp., *Onychocella inelegans*, *O. matrona*, and *Woodipora disparilis* are very common, as is *Sparsicavea* spp.

BRIEF DESCRIPTIONS OF EXTANT SECTIONS

(See Figure 9 for relative stratigraphic positions of sections.)

WEYBOURNE HOPE-OLD BUTTS GAP (TG 1115 4369-1236 4362) [Figure 3]
Chalk exposed at the base of the Pleistocene cliffs between Weybourne Hope and Old Butts Gap. 17m of mostly soft white chalk containing a hardground complex rich in oysters. Several prominent flint bands with distinctive forms, ranging from tabular to nodular in shape.

KESWICK QUARRY (TG 2120 0485)
[Figure 4]
Disused quarry on east side of Mill Road. 15m of mostly soft white chalk with occasional hardgrounds. Several prominent flint bands with distinctive forms, ranging from tabular to nodular in shape.

EATON TUNNELS SECTION (TG 2090 0640) [Figure 5]
Chalk exposed above and inside two tunnels in wooded ground north of Greenways. 13m of mostly soft, commonly iron-stained brown/white chalk with occasional hardgrounds. Several prominent flint bands with distinctive forms, ranging from tabular to nodular in shape.

WHIFFLER ROAD, NORWICH (TG 2120 1070) [Figure 6]
Exposure behind factory on the industrial estate. 4.5m of rarely nodular, soft white chalk containing four nodular flint bands.

HARFORD BRIDGES Complex of largely overgrown pits north of the Ely-Norwich railway line.
Two sections found:
HBR 1 (TG 2188 0576) [Figure 6]
Exposure at top of the old pit beside the golf course. 2.25m of blocky hard white chalk containg numerous oysters and scattered black nodular flints.
HBR 2 (TG 2200 0569)
Small tufa encrusted face with an adit in centre of wooded area of former pit complex. 1.5m of hard nodular chalk which yielded the lowest record of the terebratulid brachiopod *Carneithyris carnea* (J. Sowerby) which characterises the overlying Beeston Chalk.

WEYBOURNE HOPE EAST (TG 1290 4360-1390 4350) [Figure 6]
Discontinuous chalk exposure at the base of the Pleistocene cliffs between Old Butts Gap and Old Hithe (Sheringham). 7m of soft white chalk (rarely nodular) with several strong black nodular flint bands.

## BEESTON CHALK

Exposures logged at: Caistor St. Edmund; Bracondale, Norwich; Frettenham (x2); and St. James Hollow.

BOUNDARIES

Lower: Immediately above the hardground of the Main Catton

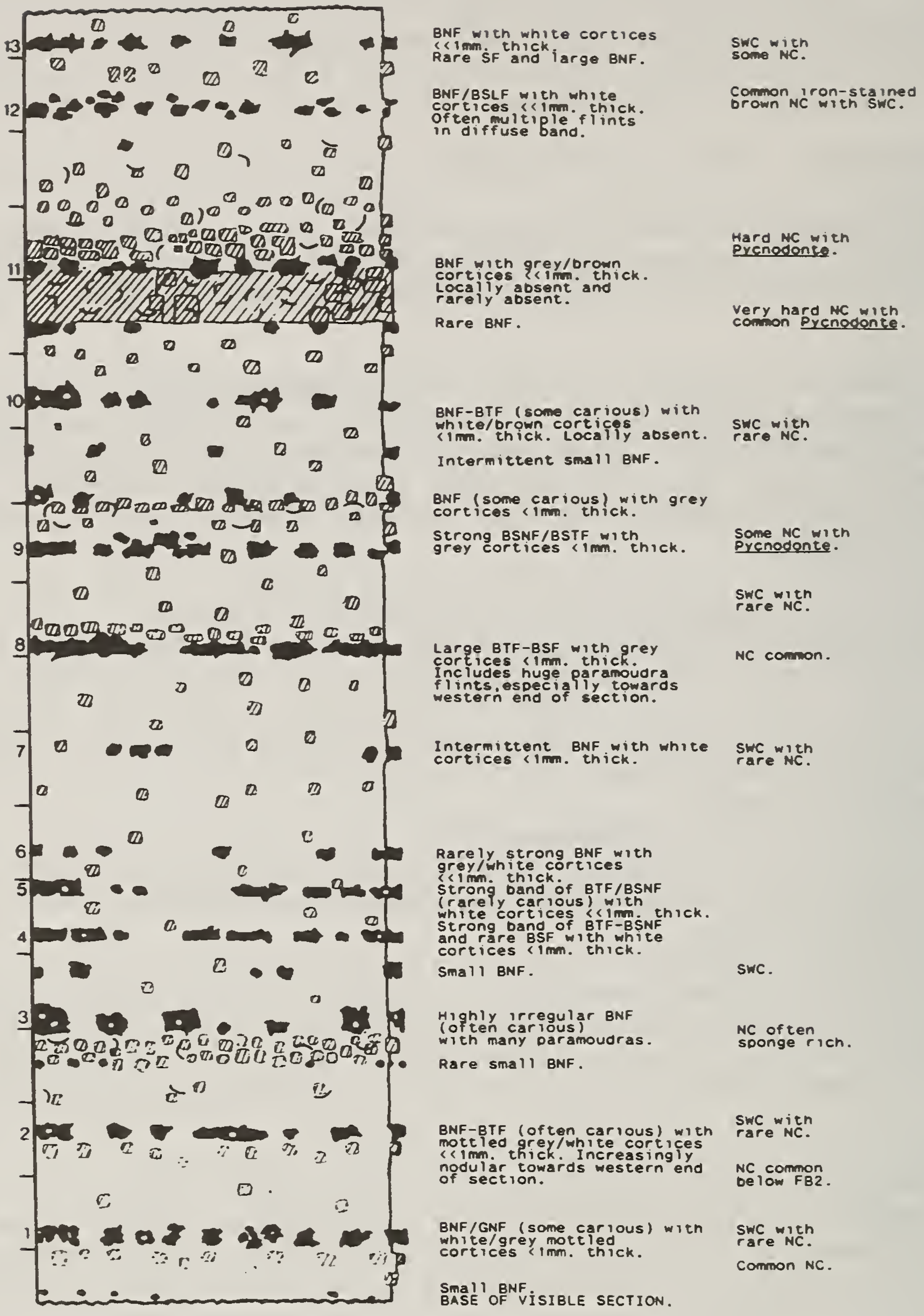
13
12
11
10
9
8
7
6
5
4
3
2
1
BNF with white cortices <<1mm. thick. Rare SF and large BNF.
SWC with some NC.
BNF/BSLF with white cortices <<1mm. thick. Often multiple flints in diffuse band.
Common iron-stained brown NC with SWC.
Hard NC with Pycnodonte.
BNF with grey/brown cortices <<1mm. thick. Locally absent and rarely absent.
Very hard NC with common Pycnodonte.
Rare BNF.
BNF-BTF (some carious) with white/brown cortices <1mm. thick. Locally absent.
SWC with rare NC.
Intermittent small BNF.
BNF (some carious) with grey cortices <1mm. thick.
Strong BSNF/BSTF with grey cortices <1mm. thick.
Some NC with Pycnodonte.
SWC with rare NC.
Large BTF-BSF with grey cortices <1mm. thick. Includes huge paramoudra flints,especially towards western end of section.
NC common.
Intermittent BNF with white cortices <1mm. thick.
SWC with rare NC.
Rarely strong BNF with grey/white cortices <<1mm. thick.
Strong band of BTF/BSNF (rarely carious) with white cortices <<1mm. thick.
Strong band of BTF-BSNF and rare BSF with white cortices <1mm. thick.
Small BNF.
SWC.
Highly irregular BNF (often carious) with many paramoudras.
NC often sponge rich.
Rare small BNF.
BNF-BTF (often carious) with mottled grey/white cortices <<1mm. thick. Increasingly nodular towards western end of section.
SWC with rare NC.
NC common below FB2.
BNF/GNF (some carious) with white/grey mottled cortices <1mm. thick.
SWC with rare NC.
Common NC.
Small BNF.
BASE OF VISIBLE SECTION.

FIGURE 3 Diagrammatic five-metre wide section of the chalk exposed on the north Norfolk coast between Weybourne Hope (TG 1115 4369) and Old Butts Gap (TG 1236 4362) [After Pitchford 1989, Figure 1.6]. Symbols and abbreviations as in Figure 2.

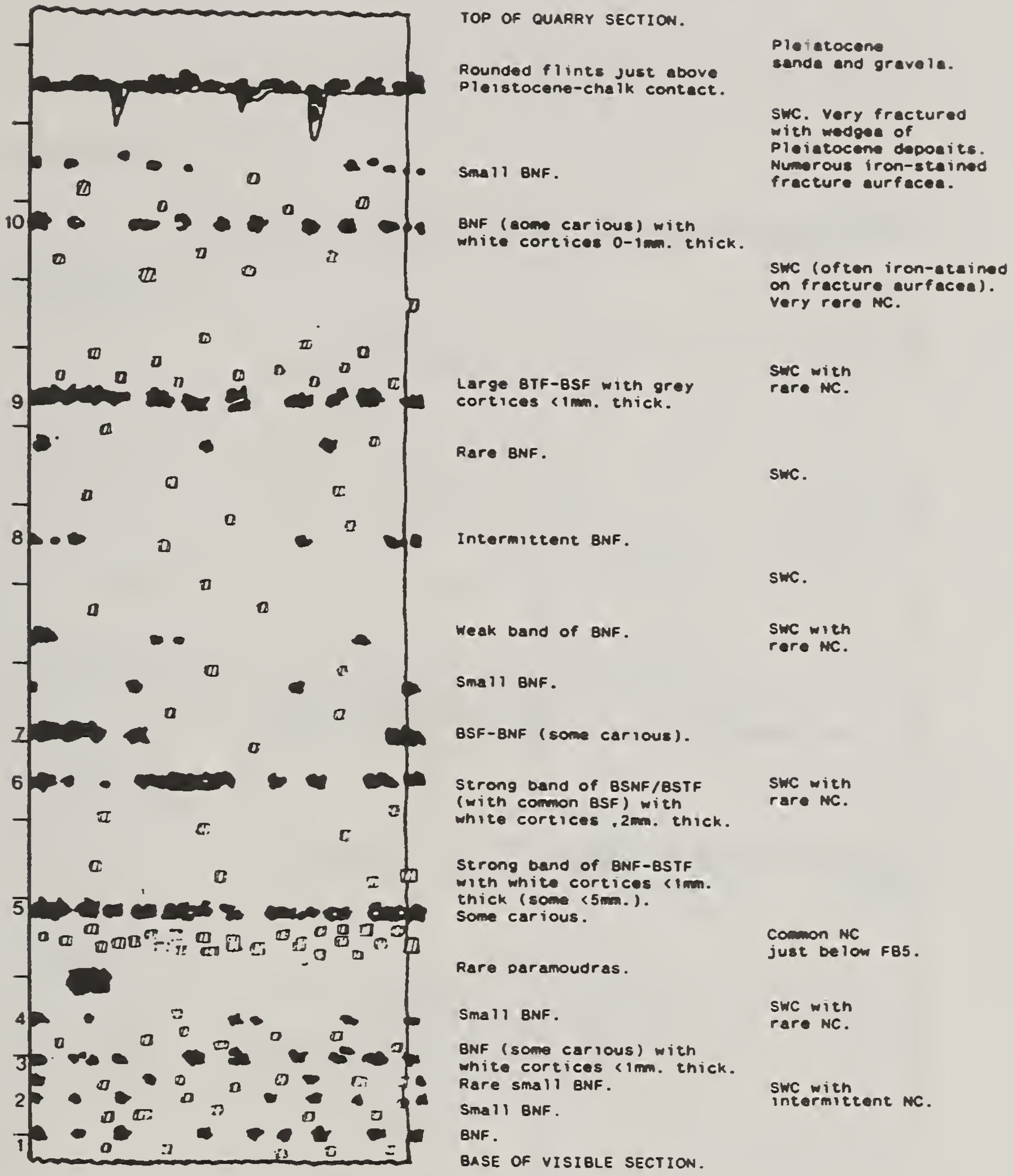
TOP OF QUARRY SECTION.
Pleistocene sands and gravels.
Rounded flints just above Pleistocene-chalk contact.
SWC. Very fractured with wedges of Pleistocene deposits. Numerous iron-stained fracture surfaces.
Small BNF.
10
BNF (some carious) with white cortices 0-1mm. thick.
SWC (often iron-stained on fracture surfaces). Very rare NC.
9
Large BTF-BSF with grey cortices <1mm. thick.
SWC with rare NC.
Rare BNF.
SWC.
8
Intermittent BNF.
SWC.
Weak band of BNF.
SWC with rare NC.
Small BNF.
7
BSF-BNF (some carious).
6
Strong band of BSNF/BSTF (with common BSF) with white cortices ,2mm. thick.
SWC with rare NC.
Strong band of BNF-BSTF with white cortices <1mm. thick (some <5mm.). Some carious.
5
Common NC just below FB5.
Rare paramoudras.
4
Small BNF.
SWC with rare NC.
3
BNF (some carious) with white cortices <1mm. thick.
Rare small BNF.
2
SWC with intermittent NC.
Small BNF.
1
BNF.
BASE OF VISIBLE SECTION.

FIGURE 4 Diagrammatic five-metre wide section of the chalk at Keswick Quarry (TG 2120 0485) [After Pitchford 1989, Figure 1.10]. Symbols and abbreviations as in Figure 2.

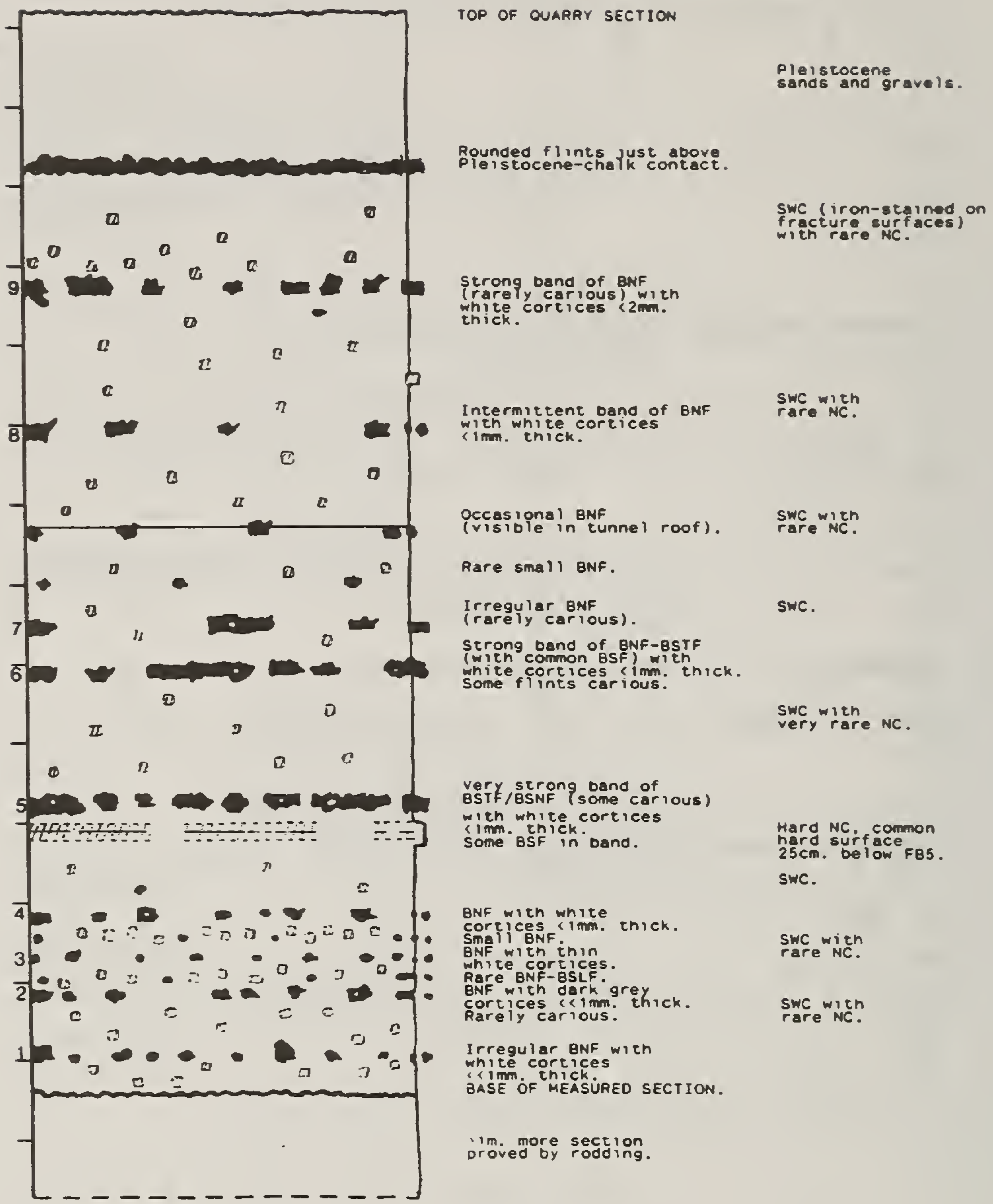
TOP OF QUARRY SECTION
Pleistocene sands and gravels.
Rounded flints just above Pleistocene-chalk contact.
SWC (iron-stained on fracture surfaces) with rare NC.
9
Strong band of BNF (rarely carious) with white cortices <2mm. thick.
Intermittent band of BNF with white cortices <1mm. thick.
8
SWC with rare NC.
Occasional BNF (visible in tunnel roof).
SWC with rare NC.
Rare small BNF.
7
Irregular BNF (rarely carious).
SWC.
6
Strong band of BNF-BSTF (with common BSF) with white cortices <1mm. thick. Some flints carious.
SWC with very rare NC.
5
Very strong band of BSTF/BSNF (some carious) with white cortices <1mm. thick. Some BSF in band.
Hard NC, common hard surface 25cm. below FB5.
SWC.
4
BNF with white cortices <1mm. thick.
3
Small BNF.
BNF with thin white cortices.
SWC with rare NC.
2
Rare BNF-BSLF.
BNF with dark grey cortices <<1mm. thick. Rarely carious.
SWC with rare NC.
1
Irregular BNF with white cortices <<1mm. thick.
BASE OF MEASURED SECTION.
>1m. more section proved by rodding.

FIGURE 5 Diagrammatic five-metre wide section of the chalk at Eaton Tunnels (TG 2090 0640) [After Pitchford 1989, Figure 1.13]. Symbols and abbreviations as in Figure 2.

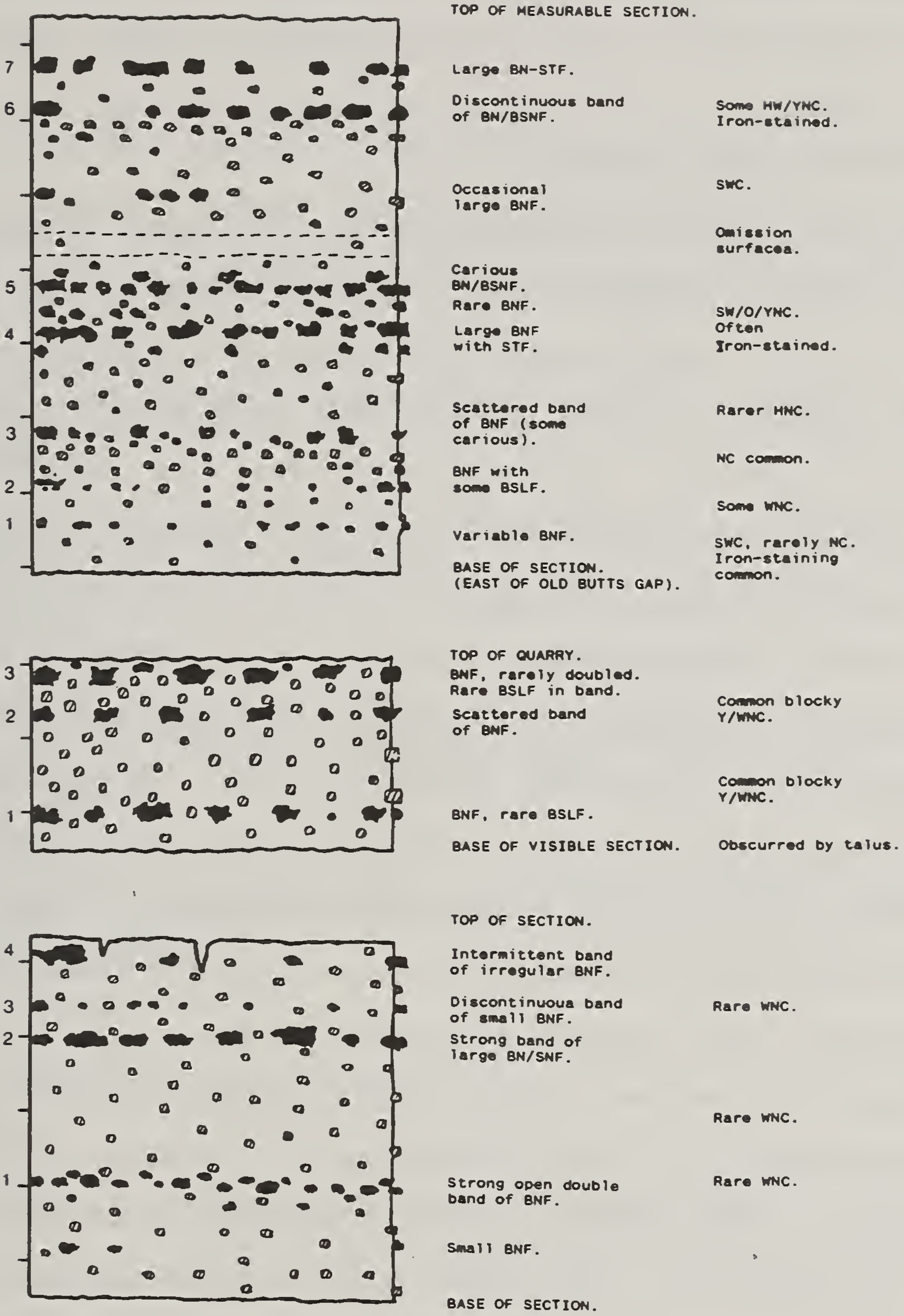
TOP OF MEASURABLE SECTION.
7
Large BN-STF.
6
Discontinuous band of BN/BSNF.
Some HW/YNC. Iron-stained.
Occasional large BNF.
SWC.
Omission surfaces.
Carious BN/BSNF.
5
Rare BNF.
SW/O/YNC. Often Iron-stained.
4
Large BNF with STF.
Scattered band of BNF (some carious).
3
Rarer HNC.
NC common.
2
BNF with some BSLF.
Some WNC.
1
Variable BNF.
SWC, rarely NC. Iron-staining common.
BASE OF SECTION. (EAST OF OLD BUTTS GAP).
TOP OF QUARRY.
3
BNF, rarely doubled. Rare BSLF in band.
Common blocky Y/WNC.
2
Scattered band of BNF.
Common blocky Y/WNC.
1
BNF, rare BSLF.
BASE OF VISIBLE SECTION.
Obscurred by talus.
TOP OF SECTION.
4
Intermittent band of irregular BNF.
3
Discontinuous band of small BNF.
Rare WNC.
2
Strong band of large BN/SNF.
Rare WNC.
1
Strong open double band of BNF.
Rare WNC.
Small BNF.
BASE OF SECTION.

FIGURE 6 Diagrammatic five-metre wide sections of the chalk at Whiffler Road (TG 2120 1070) (bottom figure), Harford Bridges (HBR 1) (TG 2188 0576) (middle figure), and Weybourne Hope East (TG 1290 4360 - 1390 4350) (top figure) [After Pitchford 1989, figure 1.13]. Symbols and abbreviations as in Figure 2.

Sponge Bed.

Upper: The major omission surface that crops out on the foreshore 180m east of West Runton and has yielded ammonites, nests of *Echinocorys*, and saurian vertebrae (Peake and Hancock, 1970, p. 339F).

BEESTON CHALK FAUNAL SUMMARY

The Beeston Chalk is characterised by common *Belemnitella*, numerous bands of fragments and larger individuals (up to 50cm in diameter) of the bivalve *Inoceramus* spp. and, especially, by the rich and diverse brachiopod fauna. The terebratulid *Carneithyris carnea* is numerous throughout as are the rhynchonellids *Cretirhynchia norvicensis* Pettitt and *C. arcuata* Pettitt. Other brachiopods including *Orbirhynchia* sp., *Kingenella* sp. *Magas* spp., *Kingena pentangulata* S. Woodward, and *Terebratulina* spp. are scattered throughout the division. A large suite of oysters is represented including *Acutostrea* cf. *incurva* Nilsson, *Gryphaeostrea canaliculata* (J. Sowerby), *Hyotissa semiplana*, and *Pycnodonte vesiculare*. Fragmentary remains of the bivalves *Neithea sexcostata* (S. Woodward), *Mimachlamys cretosa* (Defrance), and *Spondylus* spp. are also relatively common.

The sponge *Porosphaera sessilis* and columnals of the crinoids *Bourgueticrinus* spp. and *Austinocrinus bicoronatus* (Von Hagenow) are present. Echinoderms are well represented with *Echinocorys* spp., *Cardiaster* sp., and *Galerites* sp. often encounted. Spines of cidarid echinoids, and ophiouroid plates referable to *Ophiomusium granulosum* and *Ophiura substriata* Rasmussen also occur frequently. Bryozoans are common throughout the Beeston Chalk. Long-ranging forms such as "*Biflustra*" *argus*, *Onychocella inelegans*, *O. matrona*, *O. nysti* (Von Hagenow), and *Woodipora* *disparilis* are well represented, as is *Lunulites* spp. which becomes increasingly common higher in the division. Other plentiful forms are *Clypeina rosula*, *Pustulopora* spp., and *Meliceritites gothica* Levinsen.

## BRIEF DESCRIPTIONS OF EXTANT SECTIONS

(See Figure 9 for relative stratigraphic positions of sections.)

CAISTOR ST. EDMUND QUARRY (TG 2390 0466) [Figure 7]
Working quarry east of the Lakenham-Caistor road. 15m of highly fossiliferous soft white chalk (occasionally nodular) with several prominent bands of black tabular - black nodular flints.

BRACONDALE (NORWICH) (TG 2390 0740) [Figure 8]
Largely overgrown deep pit beside the traffic lights opposite Colmans Works. 2.8m of soft white chalk with two black nodular flint courses.

FRETTENHAM (JSS Aggregates Ltd.) (TG 2370 1670) [Figure 8]
Small faces around the edges of a pit formerly worked by drag-line (now filled in and used to store sand and gravel). 4.5m of soft white chalk containing a prominent double band of large black nodular flints.

FRETTENHAM (WM Howes Ltd.) (TG 2460 1730) [Figure 8]
Southern end of former pit complex at south end of the village. 2.5m of mostly soft white chalk containing three bands of black nodular flints.

ST JAMES HOLLOW (TG 2420 0950)
Old pit at the southern edge of Mousehold Heath below the prison. Small exposure of soft yellow chalk at base of wooded slope above playground.

## PARAMOUDRA CHALK

Exposure logged at: Whitlingham.

## BOUNDARIES

*Lower*: Immediately above the major omission surface that crops out on the foreshore 180m east of West Runton (Peake and Hancock, 1970, p. 339F).

*Upper*: At the level of a chalkstone with abundant *Echinocorys pyramidata* Portlock sensu Wright and sporadic *Belemnitella* represented by a mass of vertically derived flints and chalk lumps at the low-water mark, 150m west of the end of the promenade at the foot of the road down the cliff at Overstrand

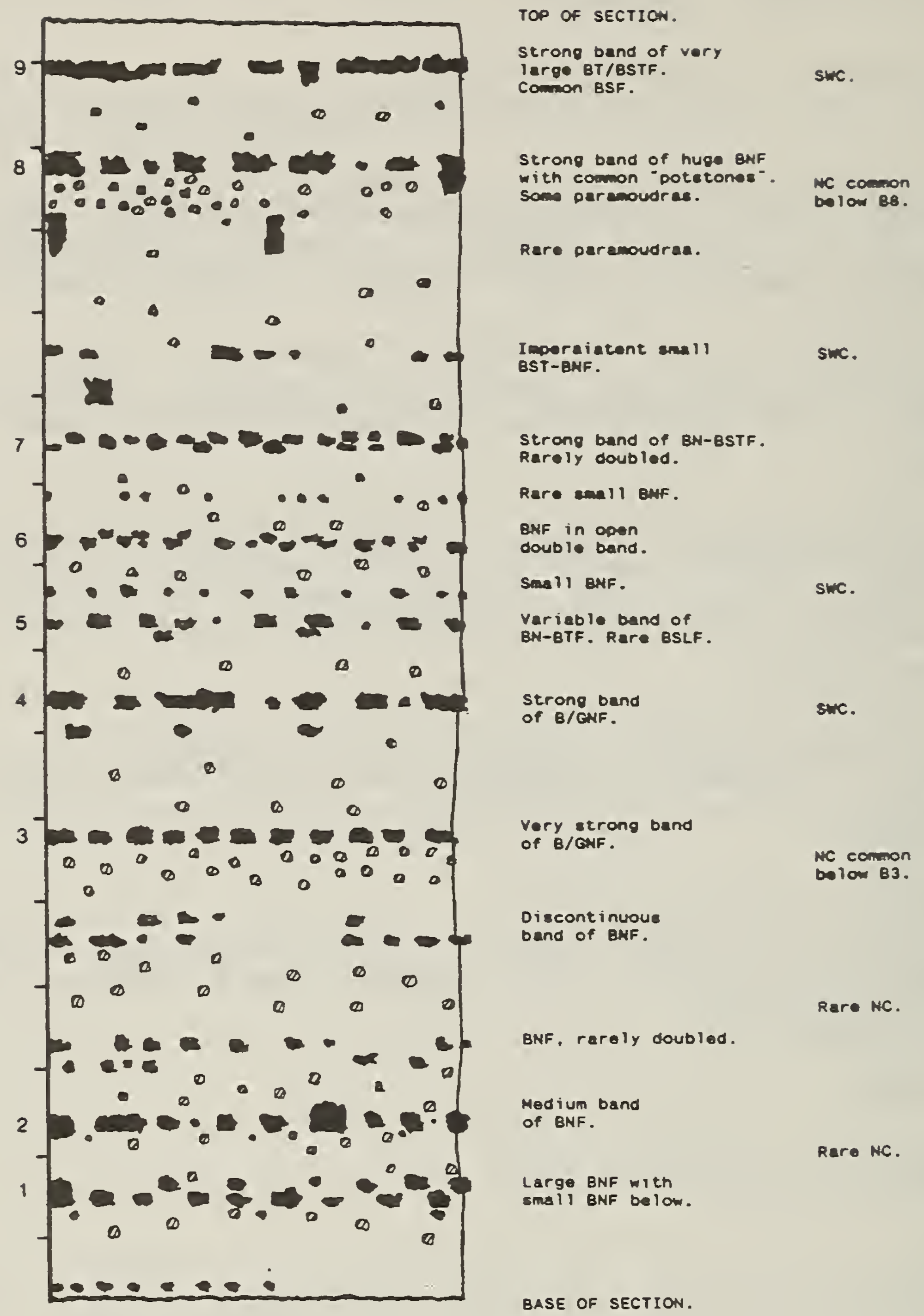
TOP OF SECTION.
9
Strong band of very large BT/BSTF. Common BSF.
SWC.
8
Strong band of huge BNF with common "potstones". Some paramoudras.
NC common below B8.
Rare paramoudras.
Impersistent small BST-BNF.
SWC.
7
Strong band of BN-BSTF. Rarely doubled.
Rare small BNF.
6
BNF in open double band.
Small BNF.
SWC.
5
Variable band of BN-BTF. Rare BSLF.
4
Strong band of B/GNF.
SWC.
3
Very strong band of B/GNF.
NC common below B3.
Discontinuous band of BNF.
Rare NC.
BNF, rarely doubled.
2
Medium band of BNF.
Rare NC.
1
Large BNF with small BNF below.
BASE OF SECTION.

FIGURE 7 Diagrammatic five-metre wide section of the chalk at Caistor St. Edmund Quarry (TG 2390 0466) [After Pitchford 1989, Figure 1.15]. Symbols and abbreviations as in Figure 2.

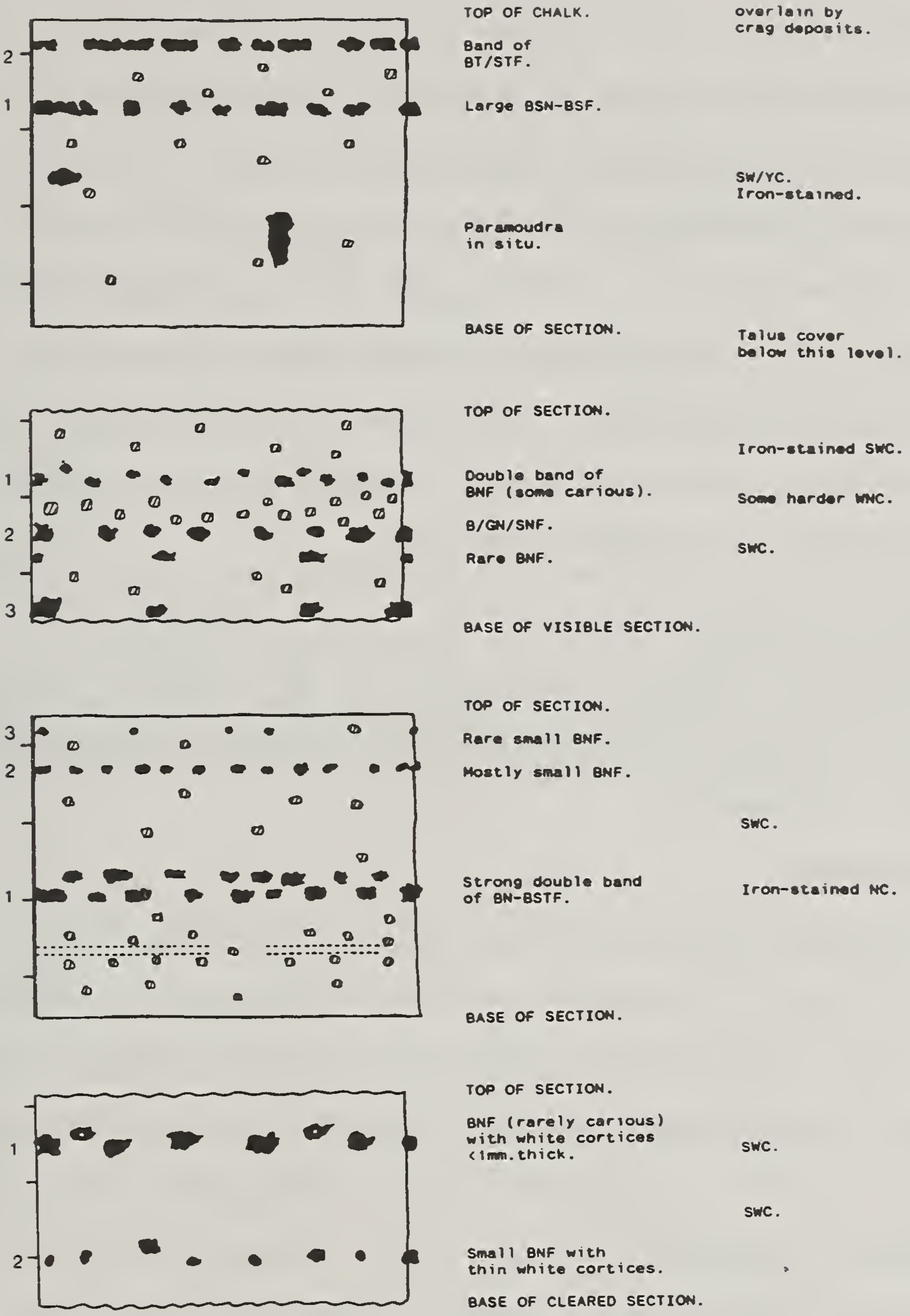

FIGURE 8 Diagrammatic five-metre wide sections of the chalk at Bracondale, Norwich (TG 2390 0740) (bottom figure), Frettenham (JSS. Aggregates) (TG 2370 1670) (second figure), Frettenham (WM. Howes) (TG 2460 1730) (third figure), and Whitlingham (TG 2681 0770) (top figure) [After Pitchford 1989, Figure 1.19]. Symbols and abbreviations as in Figure 2.

(Peake and Hancock, 1970, p. 339G; Fletcher and Wood, 1978, pp. 110; Wood, 1988, pp. 28-9).

## INTRODUCTION

This subdivision, the highest in the *Belemnitella mucronata* Zone, is characterised by chalk with columns of vertical cylindrical flints (paramoudras) up to several metres in height formed around the burrow *Bathichnus paramoudrae* Bromley, Schulz and Peake (Bromley *et al.* 1975). The fauna is dominated by small *Carneithyris* and *Cretirhynchia* transitional between *C. arcuata* and *C. limbata* (Schlotheim). Echinoids including *Echinocorys* spp. and *Micraster* spp. are relatively common as are ostreids.

## BRIEF DESCRIPTION OF EXTANT SECTIONS

(See Figure 9 for relative stratigraphic positions of sections.)

WHITLINGHAM (Colman's Pit) (TG 2681 0770) [Figure 8]

Small exposure under tree roots on the eastern side of the former quarry south of Whitlingham Lane east of the "White House". 4m of soft iron-stained yellow/orange/brown chalk containing two bands of tabular - semi-nodular black flints and an in situ. paramoudra.

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(Norwich). The fieldwork for this paper was supported by grant number GT4/86/GS/120 from the Natural Environment Research Council.

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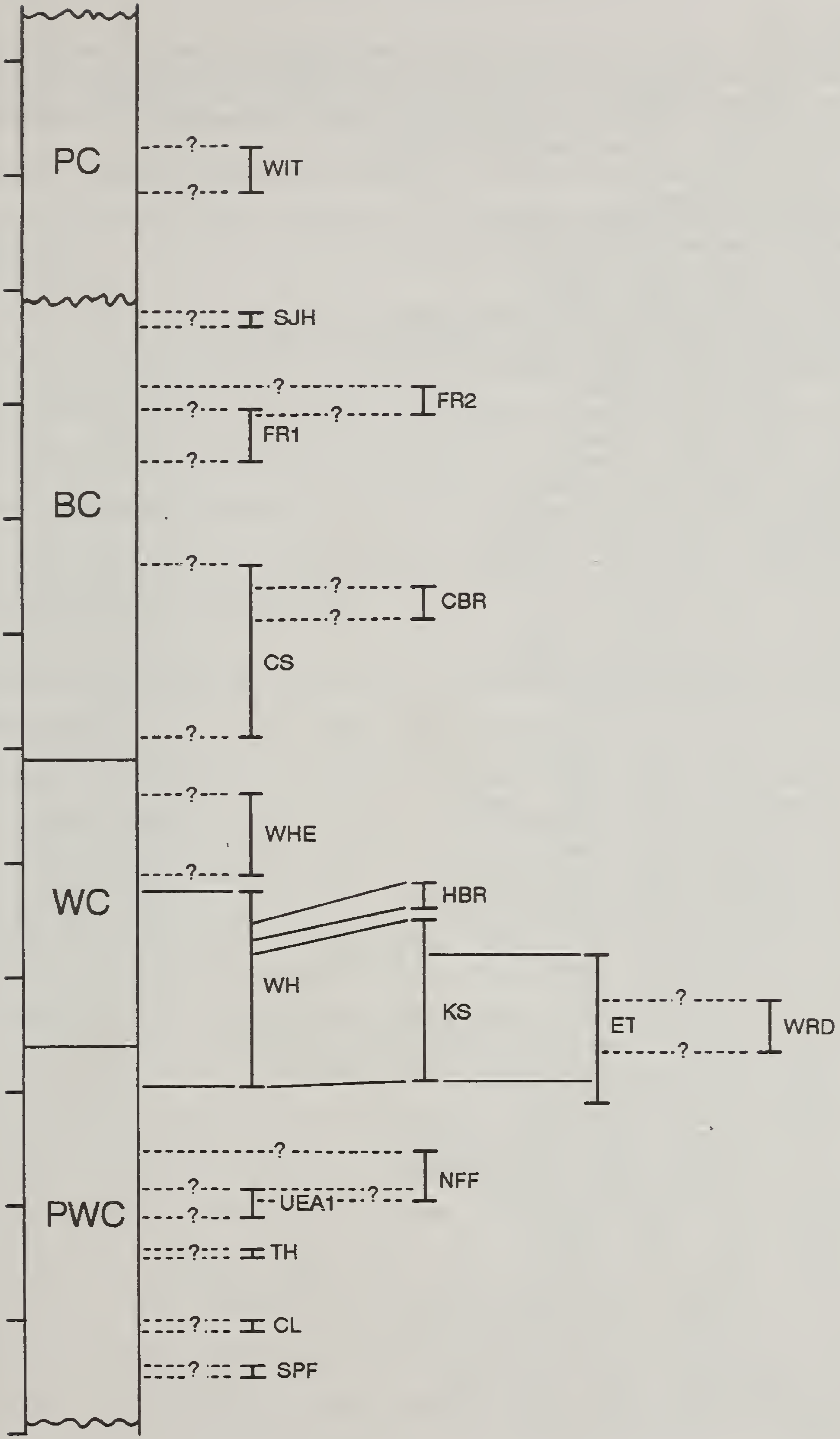
FIGURE 9 Relative stratigraphic positions of all sections described in the text. (Derived from Pitchford, 1989, Figures 1.20 and 1.21). Ticks on left side every ten metres. "?" denotes uncertainty as to stratigraphic level. Abbreviations: SPF=Spring Farm, Attlebridge; CL=Cley-next-the-sea; TH=Tharston; NFF=Newfound Farm, Cringleford; UEA1=University of East Anglia; WH=Weybourne Hope-Old Butts Gap; KS=Keswick; ET=Eaton. WHR=Whiffler Road, Hellesdon; WHE=Weybourne Hope East; HBR=Harford Bridges; CS=Caistor St. Edmund; CBR=Colmans, Bracondale; FR1=Frettenham (JSS. Aggregates); FR2=Frettenham (WM. Howes); SJH=St James Hollow; WIT=Whitlingham.

*mucronata* Chalk exposures



## APPENDIX ONE

Alphabetical index of former chalk sections in the *Belemnitella mucronata* Zone in Norfolk that are now obliterated or currently obscured (as at 1989).

Abbreviations: PWC=Pre-Weybourne Chalk; WC=Weybourne Chalk; BC=Beeston Chalk; PC=Paramoudra Chalk.

(All grid references are in 100km square TG except where otherwise indicated.)

ALDBOROUGH (1740 3580) [WC]
ALDERFORD COMMON (1290 1840) [PWC]
BLAKENEY (0330 4360) [PWC]
BLAKENEY (0230 4260) [PWC]
BURGH-NEXT-AYLSHAM (2240 2540) [WC]
CATTON GROVE (Camplings Pit) (2289 1094) [WC/BC]
CLEY GREEN (0480 4330) [PWC]
COLNEY (1802 0903) [PWC]
COLNEY (1755 0790) [PWC]
COLNEY (1700 0927) [PWC]
COLNEY (1630 0890) [PWC]
COSTESSEY (1690 1140) [PWC]
COSTESSEY (1732 1162) [PWC]
CRINGLEFORD (1940 0618) [PWC]
CRINGLEFORD (1960 0530) [PWC]
CRINGLEFORD (Cantley Pit) (1810 0810) [PWC]
CROSTWICK (2650 1640) [BC]
FLORDON (TM 1900 9720) [PWC]
HELLESDON (1950 0980) [PWC]
HEMPSTEAD (1090 3670) [PWC]
HEYDON (1200 2890) [PWC]
HORSTEAD (Little Switzerland) (2570 1730) [PC]
HORSTEAD (2560 2000) [BC]
LETHERINGSETT (0560 3980) [PWC]
LETHERINGSETT (0540 3880) [PWC]
MATLASK (1500 3330) [PWC/WC]
MORSTON (0040 4390) [PWC]
MORSTON DOWNS (0170 4370) [PWC]
NEWTON FLOTMAN (TM 2106 9830) [WC]
NORWICH (2220 0870) [WC]
NORWICH ("Baculite" Pit) (2280 0860) [WC]
NORWICH (2230 0860) [WC]
NORWICH (2380 0780) [WC]
NORWICH (Stonehills Pit) (2100 0920) [PWC/WC]
NORWICH (Earlham Limeworks) (2010 0930) [PWC/WC]
OLD CATTON (Attoes Pit) (2390 1180) [WC/BC]
RACKHEATH (2710 1550) [BC]
SHERINGHAM (1690 4320) [BC]
STOKE HOLY CROSS (2330 0260) [WC/BC]
STOKE HOLY CROSS (2536 0140) [WC/BC]
TASBURGH (TM 2030 9550) [PWC]
TAVERHAM (1474 1386) [PWC]
TAVERHAM (1490 1350) [PWC]
TAVERHAM (1620 1410) [PWC]
THORPE ST. ANDREW (Lollards Pit) (2410 0890) [BC]
THORPE ST. ANDREW (2866 0801) [PC]
THORPE ST. ANDREW (2755 0900) [PC]
TROWSE NEWTON (Crown Point Pit) (2500 0690) [BC]
UPPER SHERINGHAM (1410 4130) [WC]
UPPER SHERINGHAM (1480 4170) [WC]
WEYBOURNE (1120 4310) [WC]

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# A NEW CORRELATION WITHIN THE *BELEMNITELLA MUCRONATA* ZONE (CAMPANIAN, UPPER CRETACEOUS) OF NORFOLK

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## ABSTRACT

A new correlation is presented between the north Norfolk coastal stratotype of the Weybourne Chalk Division of the *Belemnitella mucronata* Zone (Campanian, Upper Cretaceous) and inland chalk sections at Keswick and Eaton south of Norwich, based on the occurrence of flint bands with similar morphologies at equivalent stratigraphic levels. Faunal distributions strengthen the correlation.

## CORRELATION BETWEEN THE CHALK EXPOSED AT WEYBOURNE HOPE, KESWICK, AND EATON

Two of the sections (Keswick and Eaton) are less than a kilometre apart, almost along strike, and correlate well (Figure 1). All major flint bands occur at both localities and have identical spacings and similar morphologies. The hardground at Eaton (25cm below flint band 5) that marks the top of the Pre-Weybourne Chalk (Pitchford, 1991a, p. 7) lies at the same level at Keswick (25cm below band 5). Matching these localities with the coastal section at Weybourne is less easy, but all major flint bands are present and have similar morphologies.

Flint band 9 (Eaton and Keswick), characterised by large, black sheet-like forms, matches with band 8 (Weybourne Hope). The best match is that between the black tabular flints / black semi-tabular flints of bands 6 and 7 at Eaton/Keswick with flint bands 4 and 5 at Weybourne. The strong flint band below these (5 at

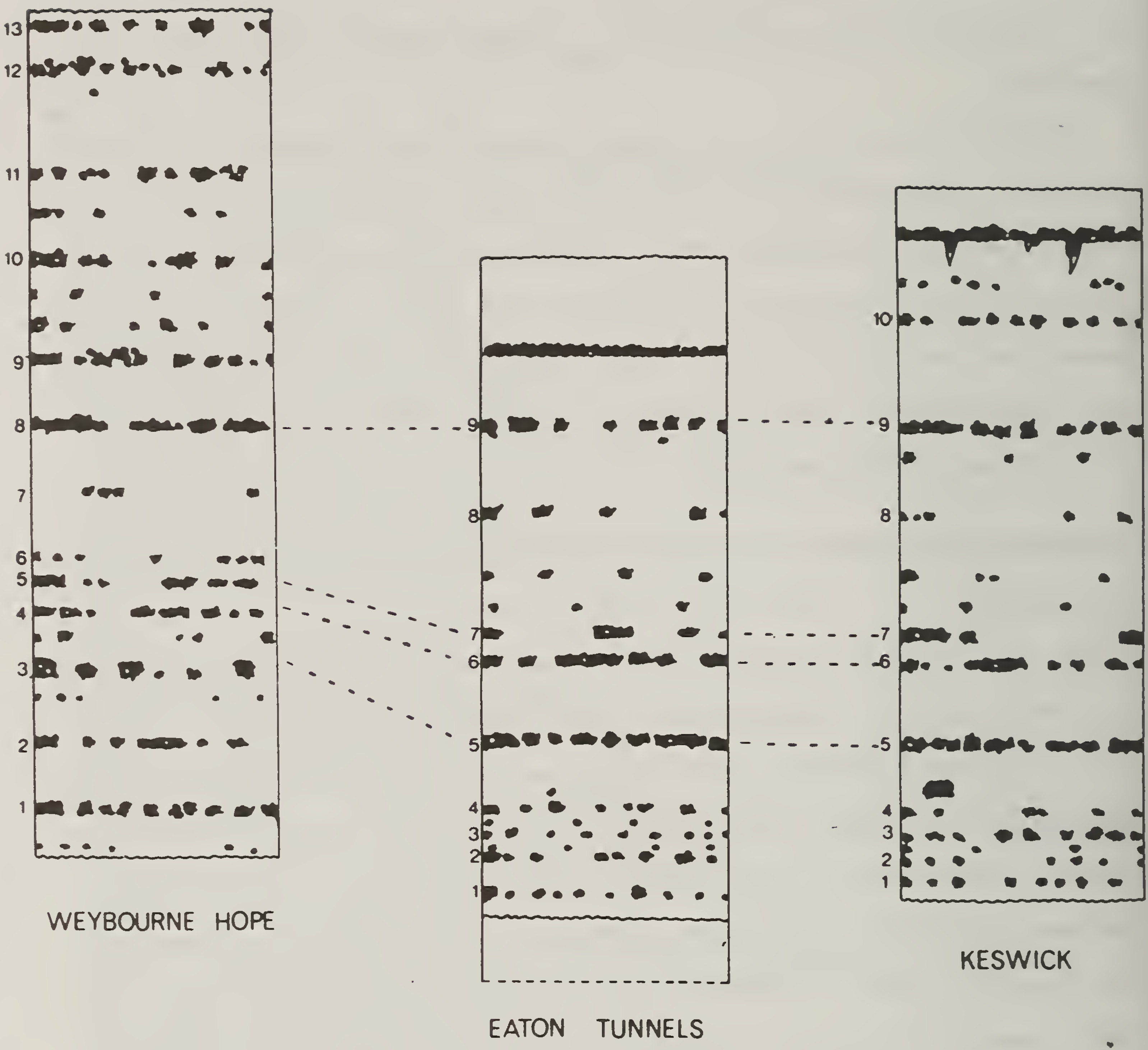

FIGURE 1 Correlation between the chalk sections visible at Eaton Tunnels, Keswick, and Weybourne Hope-Old Butts Gap (After Pitchford 1989, Figure 1.5). Numbers on left side of each section indicate the flint band notation used in the text.

Eaton and Keswick) also matches well (3 at Weybourne Hope) with its characteristic large, carious, black nodular flints and hardground/hard nodular chalk (with sponges) [the boundary between the Pre-Weybourne and Weybourne Chalks] beneath it.

Faunal distribution patterns throughout the sections are important in correlating the chalk between the localities, particularly those of oysters (including *Pycnodonte vesiculare* (Lamarck)). They are rare at Keswick and Eaton as they are at Weybourne up to a horizon just below flint band 11 where they become very common (Figure 2). This level (stratigraphically above Eaton and Keswick) has been identified in a small section of hard nodular chalk at Harford Bridges (TG 2188 0576) (Pitchford, 1991a, p. 10) about 500m north-east of Keswick, which yields numerous oysters. (For complete lists of identified faunas collected from the sections see Pitchford (1989)).

## DESCRIPTIONS OF SECTIONS

### WEYBOURNE HOPE - OLD BUTTS GAP (TG 1115 4369 - 1236 4362)

This continuous section of chalk visible at the base of the Pleistocene cliffs between Weybourne Hope and Old Butts Gap, near Cromer on the north Norfolk coast, was taken as the type section of the Weybourne Chalk division of the *Belemnitella mucronata* Zone by Peake and Hancock (1961, Figure 5). A remeasured section (Figure 2) is presented herein. The western end of the section is very disturbed and disrupted due to major collapse and slumping of the chalk, probably caused by pre-Pleistocene karstic erosion (N.B. Peake, personal communication 1988). Hence, the lowest few metres of the section are very difficult to log and it is easier to walk the section westwards from Old Butts Gap towards Weybourne Hope.

At Old Butts Gap a pair of flint bands (12 and 13) occupy the section. The lower (12), in particular, has a characteristic form containing black nodular flints and numerous black spindle-like forms. The chalk around flint band 11 is commonly quite hard and for 75cm below the band it is blocky and rich in oysters including *Pycnodonte* and *Hyotissa*.

To the west, the section is dominated by two strong flint bands which are well exposed below and immediately to the east of the old coastguard cottages (TG 1167 4365). The lower of these (8) is very continuous with many large, black sheet-like flints. Generally the chalk at this level is very soft with only rare harder nodules, although harder chalk occurs above flint band 9 and immediately underneath band 8. Below band 8 is some 2.5m of

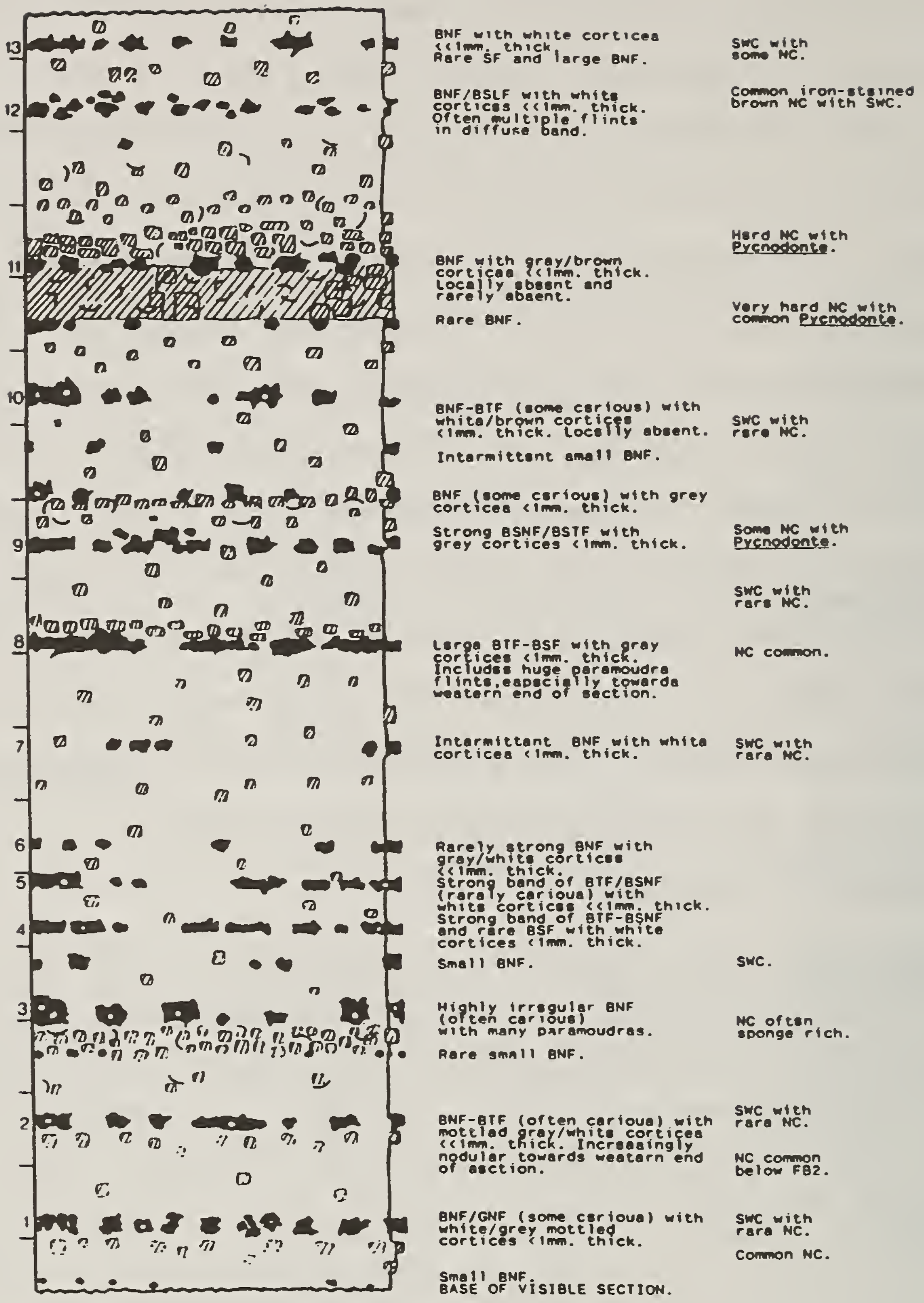
13
12
11
10
9
8
7
6
5
4
3
2
1
BNF with white cortices <<1mm. thick.
Rare SF and large BNF.
SWC with some NC.
BNF/BSLF with white cortices <<1mm. thick. Often multiple flints in diffuse band.
Common iron-stained brown NC with SWC.
Hard NC with Pycnodonte.
BNF with gray/brown cortices <<1mm. thick. Locally absent and rarely absent.
Very hard NC with common Pycnodonte.
Rare BNF.
BNF-BTF (some carious) with white/brown cortices <1mm. thick. Locally absent.
SWC with rare NC.
Intermittent small BNF.
BNF (some carious) with grey cortices <1mm. thick.
Strong BSNF/BSTF with grey cortices <1mm. thick.
Some NC with Pycnodonte.
SWC with rare NC.
Large BTF-BSF with gray cortices <1mm. thick. Includes huge paramoudra flints, especially towards western end of section.
NC common.
Intermittent BNF with white cortices <1mm. thick.
SWC with rare NC.
Rarely strong BNF with gray/white cortices <<1mm. thick.
Strong band of BTF/BSNF (rarely carious) with white cortices <<1mm. thick.
Strong band of BTF-BSNF and rare BSF with white cortices <1mm. thick.
Small BNF.
SWC.
Highly irregular BNF (often carious) with many paramoudras.
NC often sponge rich.
Rare small BNF.
SWC with rare NC.
BNF-BTF (often carious) with mottled gray/white cortices <<1mm. thick. Increasingly nodular towards western end of section.
NC common below FB2.
BNF/GNF (some carious) with white/grey mottled cortices <1mm. thick.
SWC with rare NC.
Common NC.
Small BNF.
BASE OF VISIBLE SECTION.

FIGURE 2 Diagrammatic five-metre wide section of the chalk exposed on the north Norfolk coast between Weybourne Hope (TG 1115 4369) and Old Butts Gap (TG 1236 4362) [After Pitchford 1989, Figure 1.6]. Scale bars on left side in metres. Numbers on left-hand side indicate flint band notation used in the text. Flints are solid black (except when carious). SWC=soft white chalk; NC=nodular chalk; BNF=black nodular flints; GNF=grey nodular flints; BSNF=black nodular flints; BSTF=black semi-tabular flints; BTF=black tabular flints; BSLF=black spindle-like flints; BSF=black sheet flints.

mostly soft white chalk with rare flints, beneath which is a series of closely spaced flint bands. Of these, 5 and 4 are the strongest containing locally carious, black tabular / semi-tabular flints and together forming a useful marker for correlation.

The next major flint band (3) is very characteristic, containing large, irregular, black nodular flints. The nodular chalk which crops out beneath it marks the top of the Pre-Weybourne Chalk of the *mucronata* Zone. The beds below this level are very disturbed and difficult to trace laterally. However, two bands (2 & 1) have been recognised, although the lower (1) is often obscured by shingle. Flints in band 2 are variable, ranging from carious, black nodular forms (increasingly common towards Weybourne) to carious, black tabulates. Band 1 contains (rarely carious) large, black/grey nodular fints.

KESWICK QUARRY (TG 2120 0485)

The section (Figure 3) measured at this disused quarry, 3km south of Norwich, is a composite achieved by correlating flint bands and chalk from the various faces in the quarry. (For comparison see Wood, 1988, Figure 4). The section is characterised by bands of black nodular - black semi-nodular flints interspersed with bands of laterally impersistent, small, black nodular flints. The chalk, particularly towards the top of the faces, is often stained yellow/orange/brown in colour by the downward percolation of iron-rich waters from the overlying sands and gravels.

The top of the chalk has been affected by cryoturbation with frost-wedging, frost-festooning, and solution pipes filled with the overlying Pleistocene sands and gravels well developed. The chalk is very soft with rare harder nodules. Two strong flint bands occur within the upper part of the section, the lower (9) being particularly characteristic with many large, black nodular - black semi-tabular flints and some sheet-like forms.

Strong flint bands are absent in the middle of the section, the white chalk being mostly very soft and iron-stained on fracture surfaces. Below is a double band of flints (7 & 6). The upper (7) is laterally discontinuous. Both contain many large, black semi-tabular flints and relatively common, sometimes carious, black sheet-like flints.

The largely talus-covered base of the section (exposed in the east face only) contains only one strong band (5). This is highly characteristic with very large, sometimes carious, black nodular - black semi-tabular flints and is readily recognisable at Weybourne (flint band 3) and Eaton (flint band 5). The chalk below the band is hard and nodular, particularly about 25cm below. This marks the boundary between the Weybourne and Pre-Weybourne Chalk Divisions of the *mucronata* Zone. The basal 3m of mostly soft white chalk with rare nodular bands contains diffuse bands of predominantly small, black nodular flints.

EATON TUNNELS SECTION (TG 2090 0640)

At Eaton, 3km south-west of Norwich, 13m of chalk is exposed in and above the entrances of two tunnels of the old Eaton Limeworks. The section logged by the author (Figure 4) has previously been measured by Leeder (Hornby et al., 1973, Figure 1) and is also figured in Wood 1988 (Figure 3).

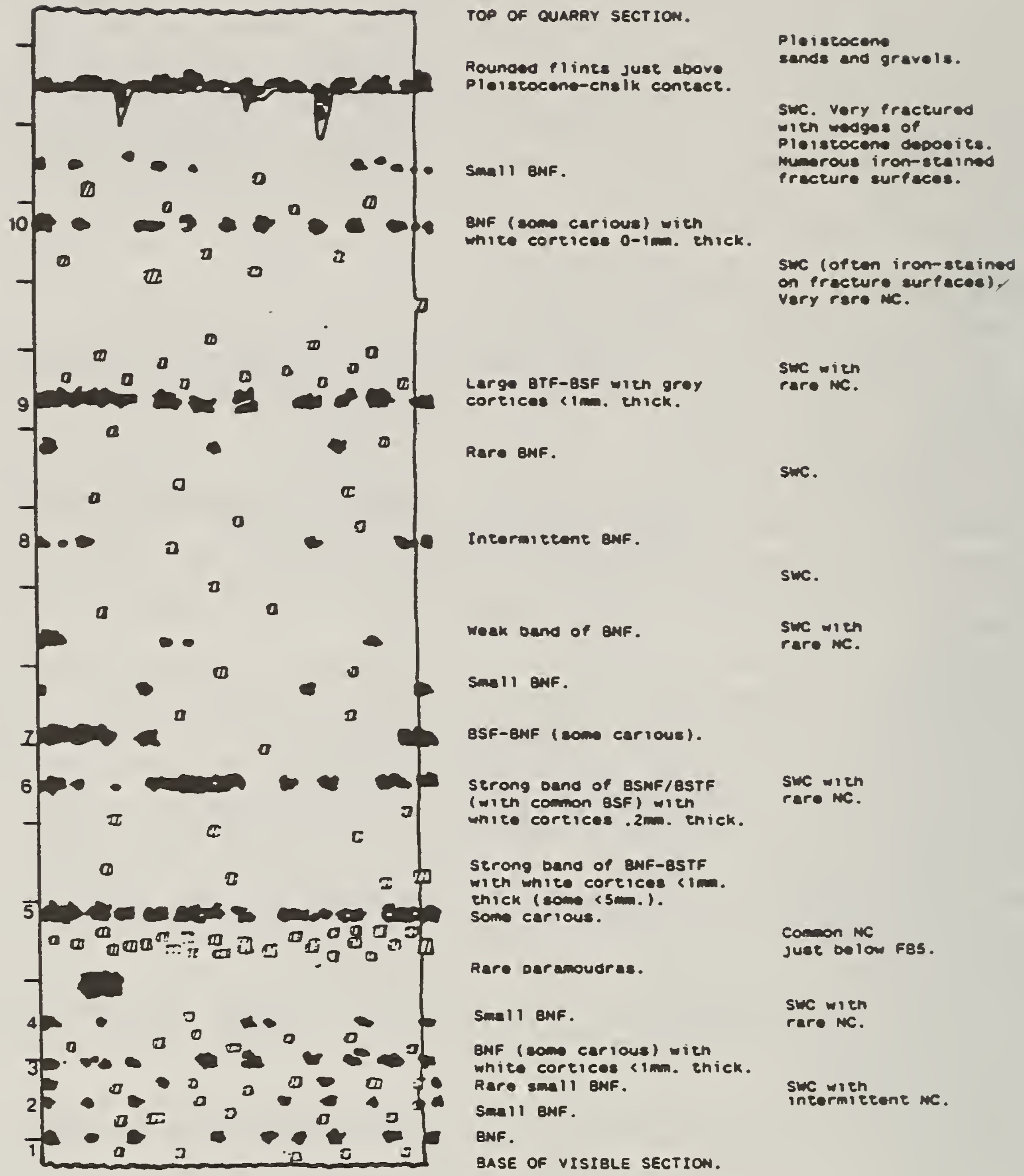
TOP OF QUARRY SECTION.
Pleistocene sands and gravels.
Rounded flints just above Pleistocene-chalk contact.
SWC. Very fractured with wedges of Pleistocene deposits. Numerous iron-stained fracture surfaces.
Small BNF.
10
BNF (some carious) with white cortices 0-1mm. thick.
SWC (often iron-stained on fracture surfaces), Very rare NC.
SWC with rare NC.
9
Large BTF-BSF with grey cortices <1mm. thick.
Rare BNF.
SWC.
8
Intermittent BNF.
SWC.
Weak band of BNF.
SWC with rare NC.
Small BNF.
7
BSF-BNF (some carious).
6
Strong band of BSNF/BSTF (with common BSF) with white cortices .2mm. thick.
SWC with rare NC.
Strong band of BNF-BSTF with white cortices <1mm. thick (some <5mm.). Some carious.
5
Common NC just below FBS.
Rare paramoudras.
SWC with rare NC.
4
Small BNF.
3
BNF (some carious) with white cortices <1mm. thick.
Rare small BNF.
SWC with intermittent NC.
2
Small BNF.
1
BNF.
BASE OF VISIBLE SECTION.

FIGURE 3 Diagrammatic five-metre wide section of the chalk at Keswick Quarry (TG 2120 0485) [After Pitchford 1989, Figure 1.10]. Symbols and abbreviations as in Figure 2.

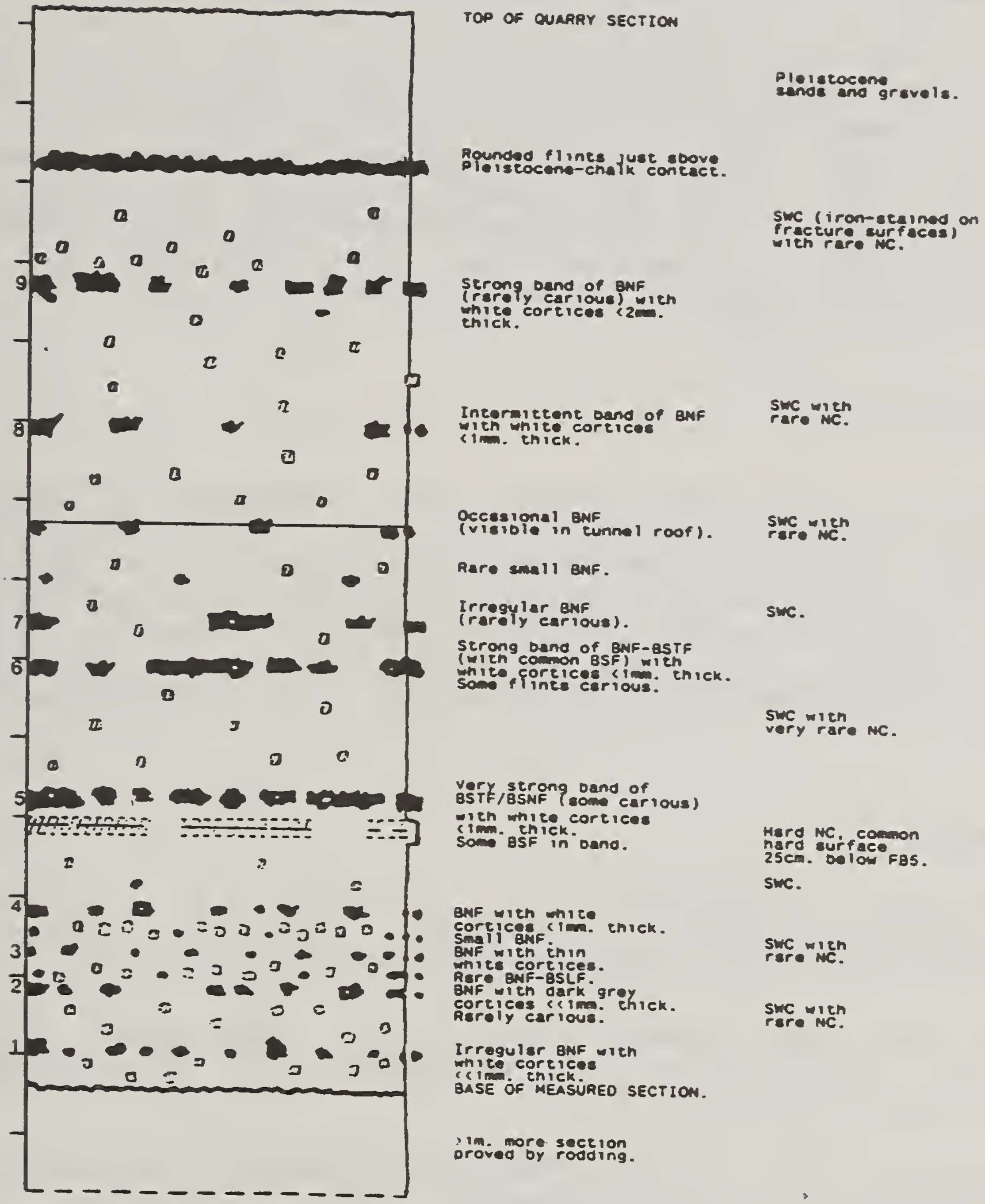
TOP OF QUARRY SECTION
Pleistocene sands and gravels.
Rounded flints just above Pleistocene-chalk contact.
SWC (iron-stained on fracture surfaces) with rare NC.
9
Strong band of BNF (rarely carious) with white cortices <2mm. thick.
8
Intermittent band of BNF with white cortices <1mm. thick.
SWC with rare NC.
Occasional BNF (visible in tunnel roof).
SWC with rare NC.
Rare small BNF.
7
Irregular BNF (rarely carious).
SWC.
6
Strong band of BNF-BSTF (with common BSF) with white cortices <1mm. thick. Some flints carious.
SWC with very rare NC.
5
Very strong band of BSTF/BSNF (some carious) with white cortices <1mm. thick. Some BSF in band.
Hard NC, common hard surface 25cm. below FB5.
SWC.
4
BNF with white cortices <1mm. thick.
Small BNF.
3
BNF with thin white cortices.
SWC with rare NC.
2
Rare BNF-BSLF.
BNF with dark grey cortices <<1mm. thick. Rarely carious.
SWC with rare NC.
1
Irregular BNF with white cortices <<1mm. thick.
BASE OF MEASURED SECTION.
>1m. more section proved by rodding.

FIGURE 4 Diagrammatic five-metre wide section of the chalk at Eaton Tunnels (TG 2090 0640) [After Pitchford 1989, Figure 1.13]. Symbols and abbreviations as in Figure 2.

The white chalk above the tunnel entrances is highly fractured and is sometimes stained brown/yellow, especially on fracture surfaces, due to percolation of iron-rich waters from the overlying Pleistocene sands and gravels. A prominent band of black nodular - black semi-tabular flints is visible 3m above the tunnel entrances together with weaker, laterally impersistent, bands of mostly small, black nodular flints.

The section within the tunnels is dominated by two very strong flint bands (5 & 6) which both have characteristic forms. The higher band (6) is composed of black nodular - black semi-tabular flints (some carious) and rarer, black sheet-like forms. Band 5 is very strongly developed with many very large, black semi-tabular / semi-nodular flints and black sheet flints. The chalk below the flint band is hard and the hardground developed 25cm below the flint forms the boundary between the Pre-Weybourne and Weybourne Chalks. At other levels the chalk is mostly soft and white on freshly exposed surfaces. In places near the base of the section nodular chalk occurs between the bands of mostly small, black nodular flints.

## ACKNOWLEDGEMENTS

I thank Mr. W.M. Howes (Howes Lime Company Ltd.) for allowing me access to Keswick Quarry and Mr. N.B. Peake (Norwich) for his help with logging the section at Weybourne. I am indebted to Dr. C.R.C. Paul (Liverpool University) who acted as my supervisor during the tenure of the Ph.D. research degree on which this paper is based. The fieldwork for this paper was supported by grant number GT4/86/GS/120 from the Natural Environment Research Council.

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# THE MAASTRICHTIAN IN NORFOLK

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## ABSTRACT

A fauna of undoubted Maastrichtian age has recently been recovered from boreholes drilled to prove the foundations of a bridge for a proposed new river crossing at Wroxham. The new material, besides substantiating the long suspected course of the Maastrichtian subcrop in Norfolk, establishes a new palaeoenvironmental setting for the Norfolk Lower Maastrichtian.

## THE NORFOLK MAASTRICHTIAN

The Maastrichtian occurs in a series of glacially transported rafts on the North Norfolk coast between Overstrand and Bacton. Inland, it is also known to crop out in the river bed near Bramerton, and macro-fossils collected from previous temporary excavations near Wroxham have demonstrated its presence there.

Today, the main exposure is on the coast at Sidestrand, though there were superb exposures at Trimingham until the mid-part of this century. There seem never to have been any substantial permanent inland exposures.

The Norfolk succession represents only the lower European Maastrichtian (Schulz, 1979). It is divided into seven units based on the faunal and lithological content of the main coastal exposures, (Table 1). The sequence displayed has not previously been matched with any section known elsewhere.

Table 1: Stratigraphy

Summary of the sequence, and proven thicknesses of the seven members of the Norfolk lower Maastrichtian constructed from the sections at Overstrand, Sidestrand, and Trimingham, (adapted from Peake and Hancock, 1961):

The measurements were originally given in Imperial units, which are shown as well.

| | Metric | Imperial |
|---|---|---|
| Tuffeau | 0.10 | 0′4" |
| Grey Beds | 0.90 | 3.0" |
| White Chalk with "*Liostrea*" *lunata* | 3.80 | 12′6" |
| White Chalk without "*Liostrea*" *lunata* | 0.60 | 2′0" |
| Sponge Beds + marl bands | 3.65 | 12′0" |
| *Porosphaera* Beds | 4.30 | 14′0" |
| Pre-*Porosphaera* Beds | 3.65 | 12′0" |
| Actual demonstrable thickness | 17.00 | 55′10" |
| Total estimated thickness | 25.90 | 85′0" |

In detail too, the units show faunal and lithological features that have hitherto been thought to be unique to these coastal exposures. It is not intended that this paper should describe them in detail. However, it is pertinent to review three of the more important features that make the sequence so striking.

1. With more than 260 named species recorded from them, (and perhaps half as many again awaiting study), the *Porosphaera* Beds contain the greatest faunal diversity in the Norfolk Upper Cretaceous. Moreover, the maximum size attained by nearly every member of each phylum is, almost without exception, greater here than that found anywhere else.

2. The Sponge Beds lithology is an intensely hardened limestone, grey on the beach outcrop, though weathering yellow. It contains at least six major hardgrounds. In appropriate sections, (e.g. Little Marl Point), it can be seen that these cut down through one another over distances of a few metres, indicating intense, highly localised erosion. This unit also contains the first mapable marl bands since the *Gonioteuthis* zone at Wells. Ernst (1982) has demonstrated that such marl bands are indicative of intense biological activity.

The rock is packed with the moulds of huge Hexactinellinid and Lithistid sponges that give the unit its name. Many of these are undescribed. Relatively little is known about the detailed taxonomy of the fauna from the Sponge Beds; the rock resists erosion, and collectable body fossils, (other than enormous irregular echinoids), appear only rarely at outcrop.

3. The *lunata* beds are sharply delimited from the underlying member by the change in fauna (there is no hiatus in deposition),

and for the first 0.5m virtually the only species present is *'Liostrea' lunata* itself. The fauna then grades up into a community of normal diversity and density.

## NEW MATERIAL FROM THE WROXHAM BOREHOLES

During 1986/87, Norfolk County Council's Highways Department sunk in excess of twenty boreholes in and around Wroxham to investigate the foundations for a new bridge. Each borehole passed through a variable thickness of sand and gravels before passing into the underlying Chalk.

The meso-fraction was extracted from selected crushed core samples by Andrew Pitchford (University of Liverpool), by washing through sieves, and picking out specimens at low magnification using a stereoscopic microscope.

The bryozoa recovered by these procedures were shown to the author for identification, to whom their high-zonal affinities were immediately apparent.

## COMPOSITION OF THE BOREHOLE MATERIAL

The boreholes from which the material was recovered were drilled at 50m to 100m intervals along a line running WSW to ENE from approximately TG 30800, 17440 to TG 30955, 17680. This line is very nearly perpendicular to the strike of the Cretaceous sub-crop, and overlies strata of Maastrichtian age.

The actual size of each borehole sample prior to preparation is not known with any accuracy, so the abundance and diversity of fossils per unit weight in each sample is indeterminate.

Material from six of the boreholes extracted from samples by Andrew Pitchford was made available to the author. This was from boreholes numbered 10 to 16, excluding 13. The borehole numbering is that used by the laboratory staff.

## Maastrichtian Chalk

The top of some of the cores yielded an extremely hard chalk that survived more than a year's treatment with Glauber's Salt substantially intact. No untreated samples were seen by the author.

The significant species from each of the borehole samples are discussed below. A complete list of which species were recovered from each, together with further locality details is given in Appendix A.

From the species recovered from the samples it is possible to assign them to the Campanian or Maastrichtian. Using these, it is also possible to recognise units in the boreholes that match part of the coastal Maastrichtian succession, and to compare both facies and thickness.

The presence of the following species was taken to support a Maastrichtian age for the samples from which they were recovered:

*Lunulites mitra* (von Hagenow);
*Lunulites cf. goldfussi* von Hagenow;
*Onychocella hercyna* Brydone;
*Tricephalopora vermicularis* (von Hagenow)
*Terebratulina gracilis* (Schlotheim)
*Belemnella lanceolata* (Schlotheim)

The presence of significant amounts of *Inoceramus* in chalk of normal lithology was taken as a Campanian indicator because it is characteristic of the two highest members of the Norwich Chalk and absent from the lowest two members of the coastal Maastrichtian. *Inoceramus* does occur in the Sponge Beds at Sidestrand, but these have a distinctive lithology that is stratigraphically diagnostic in its own right. Most of the specimens came from samples recovered from the deepest parts of the boreholes.

The following bryozoan species are taken to be shallow water indicators where they are common:

Retiform and unattached multi-laminar Diastroporids;

Unattached unilaminar cheilostomes, (e.g. *Stichopora*);

Unattached, large Theonoids;

Free-living cerioporid cyclostomes, (e.g. *Heteropora*);

Diverse Lunulitid species.

In Norfolk, the following bryozoan species have been found only at Sidestrand:

*Crisidmonea macropora* Marsson?

A *Heteropora* sp. nov.?

A ?*Clausa* sp. nov.

A *Cellepora* sp. nov.

Though the four species referred to above have not been determined to species, (they probably represent undescribed taxa), they have been matched exactly with specimens collected by the author from Sidestrand.

The unusual abundance of *Porosphaera globularis* (Phillips) give the *Porophaera* Beds their name, though the species has a long stratigraphical range.

Using the combination of stratigraphically diagnostic species, (species known to be characteristic of Sidestrand), and the palaeoecological and lithological evidence, it is possible to make the correlations between the samples and the coastal stratigraphic units detailed below.

Samples very close to Sponge Beds in age, or slightly older, (no lower than band Q of the *Porosphaera* Beds).

| Borehole Number | Sample Number |
|---|---|
| 11 | 46 |
| 12 | 44 |
| 16 | 19 |

Samples belonging to the *Porosphaera*, or to the Pre-*Porosphaera* Beds:

| | |
|---|---|
| 10 | 52 |
| 11 | 49 |
| 12 | 50 |
| 12 | 54 |
| 16 | 53 |

The remainder are assigned to the Paramoudra Chalk.

Using these results, it is possible to estimate the thickness of the units recognised in the boreholes, and to compare them with those of the coastal succession, (Table 2). It can be seen from the table that the correspondence of the maximum possible thickness of the *Porosphaera* Beds plus Pre-*Porosphaera* Beds in borehole 12, and the known thickness at Sidestrand is closely similar. The total thickness of the capping Sponge Beds cannot be ascertained.

Table 2: Correlation of borehole and coastal successions

| Borehole | 10 | 11 | 12 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|
| Depth below OD of chalk surface | 5.25 | 4.80 | 6.30 | 16.6 | 15.5 | 9.0 |
| Depth below OD of samples | | | | | | |
| UNIT 'A' | | | | | | |
| 6.40 | | 46<br>34/50 | | | | |
| 8.30 | | | 44<br>22/30 | | | |
| 9.20 | 52<br>23/60 | | | | | |
| 9.70 | | | | | | 19<br>14/36 |
| UNIT 'B' | | | | | | |
| 11.20 | | | | | | 53<br>24/55 |
| 12.30 | | | 50<br>22/65 | | | |
| 12.80 | | | 54<br>13/30 | | | |
| 14.90 | | 49<br>20/60 | | | | |
| UNIT 'C' | | | | | | |
| 16.00 | | | | | 51<br>8/20 | |
| 17.40 | | | | 18<br>12/20 | | |
| 18.60 | | | | | 48<br>9/50 | |
| 18.80 | | | 45<br>17/60 | | | |
| 20.20 | | | | | 43<br>28/70 | |
| 26.90 | | 47<br>12/60 | | | | |

Explanation of Table 2.

The table shows the boreholes and the sample numbers of material obtained from each. The left-most column shows the depth below O.D. from which each sample in the body of the table was obtained.

Entries in the table have the format:

sample number

total number of species/total number of specimens

Hence from the table it can be seen that sample number 47 from borehole 11 yielded 60 specimens belonging to 12 species. The criteria for allocating a horizon to each sample are discussed in the text.

UNIT 'A' represents the Sponge Beds. It is at least 2 metres thick, (depth of sample 44 of borehole 12 below O.D. - depth below O.D. to chalk surface = 8.30-6.30), and possibly, but improbably, (for this borehole), as much as 6.0 metres thick, (sample 50 of borehole 12 - depth below O.D. to chalk surface = 12.30-6.30).

UNIT 'B' represents the *Porosphaera* Beds and Pre-*Porosphaera* Beds. Again, using borehole 12, sample 44, which is in Sponge Beds, and sample 45, which is in Paramoudra Chalk, it is possible to set upper and lower boundaries for the unit. Its maximum thickness is 14.90-6.40m = 8.50 metres. The thickness at Sidestrand is 7.95 metres.

UNIT 'C' is the upper Campanian Paramoudra Chalk.

## OTHER SITES IN THE NORFOLK MAASTRICHTIAN

Besides the coastal sections, there are several inland sites that have yielded material of Maastrichtian or very slightly older age. It is useful to review them to see how they might correlate with the coastal succession. The sites are described in the order in which they cross the strike, (i.e. from West to East).

1. Whitlingham Sewage Works, (TG 279 077).

In the late 1970s, excavations for new settling tanks at Whitlingham sewage works yielded numerous *Echinocorys* that were obviously of Maastrichtian age. Those shown to the author best match material since collected from about band 'S' of the *Porosphaera* Beds at Sidestrand. The excavations showed clearly that the chalk from which the specimens were recovered was not *in situ*, (P.G. Cambridge, and N.B. Peake, pers. comm.). However, from Peake and Hancock's (1970) map of the *mucronata* subzones, and of the Maastrichtian, it was clearly nearly in the correct stratigraphical position.

During the course of writing this paper, the sewage works were extended by the addition of another settling tank about one hundred metres to the East of the site seen by Cambridge and Peake. This later excavation was visited by the author together with Mr Peake. Unlike the section seen earlier, the chalk through which the new excavations passed was demonstrably *in situ*. The fauna obtained by the author from bulk samples collected for processing showed many similarities to that of the *Porosphaera* Beds, though it was clearly not the same. Exposures high in the Paramoudra Chalk are rarely seen today, and the results obtained from the sampling will be published separately (Whittlesea, in prep.). However, it is clear already that the site is stratigraphically above the famous Thorpe "cast" Bed, and below the Postwick Grove hardground complex. Indeed, the total absence of any hardgrounds in the section, which was of a considerable size, is noteworthy in itself. Presumably, the site corresponds with part of the coastal succession to the East of Cromer Pier, which, is built on top of the Thorpe "cast" Bed, (N.B. Peake, pers. comm.).

2. Bramerton Common, (TG 297 061), and Church, (TG 297 047).

Whittlesea (1985), collected extensive material from excavations for a sewage pipe that crossed Bramerton Common, but did not find *Belemnella*. This fact, together with the presence of a characteristic high Campanian fauna, led him to refrain from referring Bramerton to the Maastrichtian, though Wood (1988) has pointed out that that genus does not constitute a majority of the belemnites until well above the boundary. Ironically, the slightly older chalk at Whitlingham contains many characteristic Maastrichtian elements, though *Belemnella* is still absent. Presumably, this is due to a difference in facies. The author has since noticed that material of Sponge Beds lithology has been used in some (?)eighteenth century repairs to Bramerton parish church (Whittlesea, unpublished observation).

3. Surlingham Ferry, (TG 326 071).

Work associated with the insertion of steel sheet piling into the river bank on the North side of Surlingham Ferry yielded a soft white chalk containing abundant *Porosphaera globularis* (Phillips) (Whittlesea, unpublished data). This lithology and faunal combination is strongly reminiscent of the *Porosphaera* Beds, though obviously not diagnostic.

4. Surlingham to Brundall, (TG 312 079).

Dredging of the bed of the river Yare some years ago, brought up chalk that yielded *Echinocorys* believed to represent the Sponge Bed horizon, though the specimens did not occur in the characteristic lithology, (N.B. Peake, pers. comm.; material now in Norwich Castle Museum).

## DISCUSSION

All of these sites lay almost due South along the strike from Sidestrand and Trimingham, and should therefore overlie strata of the same age. It will be realised from the above that the expected sequence does appear to be upheld by the available evidence.

On the basis of these results it is tentatively suggested that at least the lowest three of the coastal members of the Norfolk Maastrichtian continue from Wroxham to a point South of Norwich, giving a length along the strike for the Maastrichtian subcrop of some 38 kilometres.

## PREVIOUS RESEARCH ON THE NORFOLK MAASTRICHTIAN

The inland presence of the Maastrichtian has been known for a long time, but the relationship between it, and the coastal succession has never been established before with any clarity.

This was in part due to the fact that earlier workers had not tried to extract the meso-fauna from such lithological samples as did become available, and that the macro-fossil assemblages collected were not large enough, or diverse enough, to enable detailed comparisons to be made.

However, it was also in part due to the presumed uniqueness of the coastal exposures. It was not expected that they would have any significant litho-stratigraphic correllation with other sites. This view was reinforced by the failure of the IGS borehole near Trunch, (TG 287 374) to pass through the Sponge Beds.

Peake and Hancock (1961) thought that the coastal rafts had been transported from above salt-domes in the North Sea by glaciers during the Pleistocene.

Given a sufficient thickness of salt, (about 130m), and a sufficient overburden, (900m of sediment of normal density), salt is capable of movement to form diapiric structures. Peak and Hancock envisaged that in certain parts of the North Sea there would be areas that possessed only a moderate cover of Mesozoic sediments overlying Permian Zechstein salt. In such areas the additional weight of the glacier ice could be sufficient to place the load over the threshold required to initiate the formation of halokinetic structures, (e.g. salt-domes), in the underlying strata, or to re-activate earlier ones. The upward migration of the newly mobilised salt would then assist the glacier in prising off slabs of chalk where it moved over these structures.

The possibility that such salt domes might have been active during the Cretaceous, led Peake and Hancock, (1970, page 339I), to suggest that contemporary diapirism might account for the localised diachronous erosion surfaces in the Sponge Beds.

Peake and Hancock's suggestion has led this author to speculate on some further intriguing possibilities:

All of the commercially significant hydrocarbon traps in the Chalk in the North Sea occur in structural highs resulting from diapirism in Zechstein salt, or Jurassic shales, (Hancock, 1986; Hardman and Eynon, 1978). These diapirs moved in pulses, whilst the Chalk was still accumulating, (Hardman and Kennedy, 1980).

Some salt-domes in the modern North Sea have hydrocarbon traps associated with them, from which oil and natural gas escapes onto the sea floor. The sea floor in the vicinity of leaks above salt domes is noticeably richer in marine life than the surrounding area, and the sea floor is intensely hardened and uneven, (Hovland, Judd and Maisey, 1985).

Given that the hydrocarbons in these deposits were them mature enough, it seems reasonable to suggest that a similar process could have operated in the Cretaceous, thereby accounting for the high diversity and density of the *Porosphaera* Beds. If brine leaked from such a salt dome it could cause a local, abrupt, and temporary salinity change, that only salt-tolerant species would survive. Since oysters are amongst the most stenohaline of marine invertebrates, a salinity change caused by such a mechanism could account for the abrupt appearance and gradual disappearance of *Liostrea lunata* (Nilsson) in the *lunata* Beds.

## SUMMARY

The correlation of the stratigraphy of the coastal glacial "rafts" with that of the undoubtedly *in situ* chalk seen in the Wroxham boreholes means that it is no longer necessary to postulate a remote origin for them.

Moreover, unpublished results of a detailed exercise to map the Sidestrand rafts, carried out by Warren, Whittlesea, et al., has enabled Warren (in prep.) to demonstrate that it was improbable for them to be anything other than local in origin, even without the borehole evidence. Of course, it is not doubted that the Sidestrand and Trimingham masses are rafts.

As a result it is no longer possible to think just in terms of a small area of Cretaceous sea-floor on top of a salt-dome, but instead it is necessary to take a broader perspective to include processes operating on a regional scale.

The evidence currently available represents an insufficient basis on which to arrive at a firm conclusion on the origin of the faunal and sedimentological features referred to in this paper. However, now that a more accurate grasp of the size and nature of the subcrop is known, the task of reconstructing the palaeoenvironment can at least proceed on a surer basis.

It will be particularly important for future research to find out how many of the features of the coastal succession are present inland, e.g. the diachronous erosion surfaces in the Sponge Beds, and the oyster rich beds of the *lunata* Chalk, and whether any of these really do extend as far South as Bramerton, a point which must be considered uncertain as yet.

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## APPENDIX 'A'

This list contains only those species that it has been possible to identify with sufficient confidence to satisfy the author; there remain some tens of species, (mostly bryozoa), which it has not proven possible to identify owing to the fact that they almost certainly represent undescribed taxa.

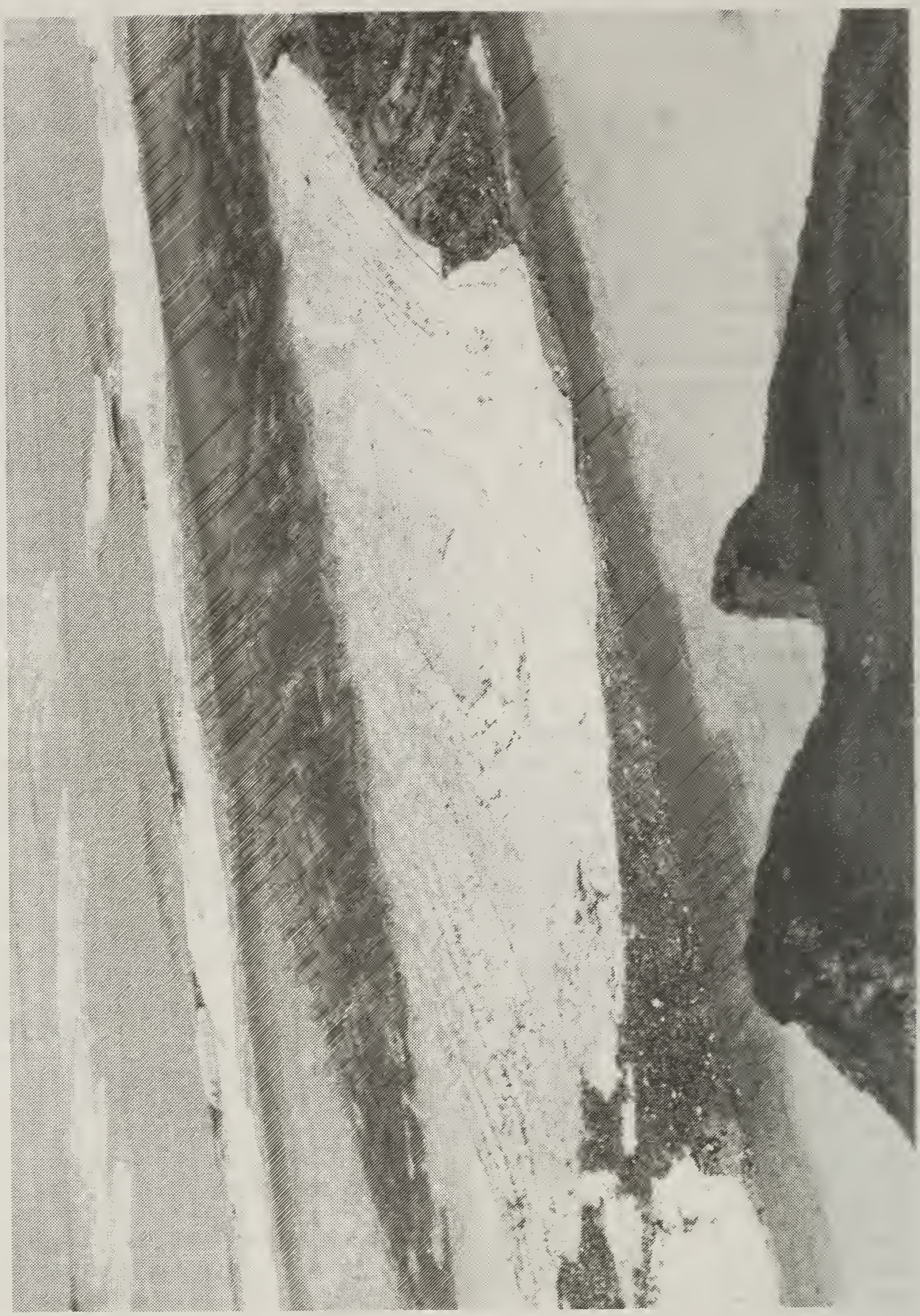
| Borehole number | 10 | 11 | | | 12 | | | | 14 | 15 | | | 16 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | 52 | 46 | 47 | 49 | 44 | 50 | 54 | 45 | 18 | 51 | 48 | 43 | 19 | 53 |
| Porifera | | | | | | | | | | | | | | |
| *Porosphaera globularis* (Phillips) | | + | + | | + | + | | | | | | + | + | + |
| *Porosphaera sessilis* Brydone | | | | | + | + | | | | | | + | | |
| *Porosphaera* sp (fusiform) | | | | | | | | | | | | | | + |
| Cyclostome bryozoa | | | | | | | | | | | | | | |
| *Diastopora* sp multi-laminar | | + | | | | | | | | | | | | |
| *Diastopora* sp (retiform) | + | | | | | | | | | | | | | |
| *Stomatopora* sp | | | | | | + | | | | | | | | |
| *Clinopora* sp | + | | | | | + | | | | | | | | |
| *Clinopora lineata* (Beissel) | | | | + | | | | | | | | | | |
| *Tervia* sp | | | | | | | | + | | | | | | |
| *Pustulopora* sp | + | | | | | + | + | + | | | + | | + | |
| *Spiropora verticillata* (Goldfuss) | | | | | | + | | | | | | | | + |
| *Clausa*? sp nov.? | | + | | | | | | | | | | | | |
| *Clausa franqana* (d'Orb.) | | + | | | + | | | | | | | | | |
| Theonoid | + | | | | | | | | | | | | | |
| *Theonoa* sp | | | | | + | | | | | | | | | |
| *Hornera* sp nov. | | | | | + | | | | | | | | | + |
| *Eohornera langethalli* (von Hagenow) | | + | | | | | | | | | | | | |
| *Stigmatoechos* sp | | + | | | | | | | | | | | | |
| *Crisina lichenoides* (Goldfuss) | | | | | + | | | | | | | | | |
| *Crisidmonea* cf. *macropora* Marsson | | | | + | | | | | | | | | | + |
| *Osculipora truncata* (von Hag.) | | | | | | | | | | | | | | + |
| *Homaeosolen* sp? | + | | | | | | | | | | | | | + |
| *Meliceritites* sp | + | | + | + | | | + | | | | + | | | + |
| *Meliceritella* sp | | | + | | | | | | | | | | | |
| *Petalopora reticulata* (Marsson) | | | | | | | | + | | | | | | |
| "*Heteropora*" sp | + | | | | | | | | | | | | | |
| *Disporella irregularis* (d'Orbigny) | | | | + | | | | | | | | | | |

Appendix A contd.

| Borehole number | 10 | 11 | | | 12 | | | | 14 | 15 | | | 16 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | 52 | 46, | 47, | 49 | 44, | 50, | 54, | 45 | 18 | 51, | 48, | 43 | 19, | 53 |
| **Cheilostome bryozoa** | | | | | | | | | | | | | | |
| "*Biflustra*" *argus* d'Orbigny | + | | + | + | | + | + | + | + | | | + | + | + |
| "*Membranipora*" *hegamone* Brydone | | + | | | | | | | | | | | | |
| "*Membranipora*" *hexagona* (Goldfuss) | | + | | | | | | | | | | | | |
| *Biflustra flabelliformis* d'Orb. | | + | | | | | | | | | | | + | |
| *Stichopora* sp? | | | | | + | | | | | | | | | |
| *Callopora* sp | | | | | | + | | | | | | | | |
| *Lunulites* sp cf. *octonaria* Voigt | | | | | | | | | | | | + | + | + |
| *Lunulites mitra* (von Hag.) | + | + | | | + | | | | | | | | | |
| *Lunulites cretacea* Defrance | | | | | | | | | + | | | | + | |
| *Lunulites* cf. *goldfussi* von Hagenow | | + | | | | | | | | | | | + | |
| *Woodipora disparilis* (d'Orb.) | | + | + | + | + | + | | + | + | | | + | | + |
| *Onychocella dichotoma* (Goldfuss) | | | | | + | | | | | | | | + | |
| *Onychocella gibbosum* (Marsson) | | | | | + | | | | + | | | | | |
| *Onychocella hercyna* Brydone | | | | | + | | | | | | | | | |
| *Onychocella inelegans* (Lonsdale) | + | + | | | | | + | | + | + | + | + | | + |
| *Onychocella matrona* (von Hagenow) | | + | + | + | | + | + | + | | | | + | + | |
| *Onychocella nysti* (von Hagenow) | | + | | | + | + | | | | | | | | |
| *Onychocella mimosa* Brydone | | | | | | | + | | | | | | | |
| *Onychocella pockrandti* Voigt | | | | | | + | | | | | | | | |
| *Onychocella rowei* Brydone | + | + | | | | | | | + | | | | + | |
| *Coscinopleura* sp | | | | | | | | | | | | + | | |
| *Coscinopleura lamourouxi* (von Hagenow) | | | | | | + | | | | | | | | |
| *Tricephalopora vermicularis* (von Hagenow) | | | | | | | | | + | | | | | |
| *Pachytheca* sp | | + | | + | | | | + | | | | + | + | |
| *Porina* sp | | + | | | | | | | | | + | | + | |
| *Beisselina* sp indet. | | + | + | | | | | | | | | | | |
| *Porina allantica* Brydone | + | + | | | | | | | | | | | | |
| *Porina disticha* (Goldfuss) | | | | | | | + | | | + | + | + | | |
| *Porina* (*Rotiporina*) sp | | + | | | + | | | | | | | | | |
| "*Cellepora*" sp*** | | | | + | | | | | | | | | | |
| **Brachiopoda** | | | | | | | | | | | | | | |
| *Isocrania* sp | | | | | | | | | | | | + | | |
| *Isocrania barbata* (von Hagenow) | | | | | + | | | | | | | | | |
| *Isocrania costata* (Sowerby) | | | | | + | + | | | | | | | | |
| *Kingena pentangulata* (Woodward) | | + | | | | | | | + | | | | | |
| *Magas pumilus* Sowerby | | + | | | | | | | | | | | | |
| *Bifolium wetherelli* (Morris) | | | | | | + | | | | | | | | |
| *Cretirhynchia* sp | | | | | | | | | + | | | + | | |
| *Carneithyris subcardinalis* (Sahni) | | + | | | | | | + | + | | | + | + | |
| *Terebratulina faujassi* (Roemer) | + | | | | + | + | | | + | | | + | | |
| *Terebratulina gracilis* (Schlotheim) | + | + | | | | | | | | | | | + | |
| *Terebratulina longicollis* Steinich | | | | + | | | | | | | | | | |

Appendix A contd.

| Borehole number | 10 | 11 | | | 12 | | | | 14 | 15 | | | 16 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | 52 | 46, | 47, | 49 | 44, | 50, | 54, | 45 | 18 | 51, | 48, | 43 | 19, | 53 |
| **Bivalvia** | | | | | | | | | | | | | | |
| Bivalve in Sponge Bed lithology | | + | | | | | | | | | | | | |
| *Gyropleura inequirostrata* (Woodward) | + | | | | | | | | + | | | | | |
| *Pycondonte vesiculare* (Lamarck) | | | | | | | + | + | | | | | | + |
| *Mimachlamys cretosus* (Defrance) | | | | | + | | + | | | | | | | |
| *Neithea quinquecostata* (Woodward) | | | | | | + | | | | | | | | |
| *Pseudolima granulata* (Nilsson) | | + | | | | | | | | | | + | | |
| *Lyropecten campaniensis* (d'Orbigny) | | | | | | | | | | | | + | | |
| *Spondylus dutempleanus* d'Orbigny | | | | + | | | + | | | | | + | | |
| *Inoceramus* sp | | + | | | | | + | + | | | | + | | + |
| **Cephalopoda** | | | | | | | | | | | | | | |
| *Belemnella lanceolata* (Schlotheim) | + | + | | + | + | | | + | | | | | | + |
| **Serpulida** | | | | | | | | | | | | | | |
| *Conorca trochiformis* (von Hagenow) | | | | | | | | | | | | + | | |
| *Ditrupa* sp | | | | | | | | | | | | + | | |
| *Ditrupa canteriata* (von Hagenow) | | | | + | | | | | | | | | | |
| *Ditrupa contracta* (Sowerby) | | | | | | | | | | | | | | + |
| *Filogranula cincta* (Goldfuss) | | + | + | | | | | | | | | | | |
| *Glomerula gordialis* (Schlotheim) | | + | + | + | + | + | | + | | | | | | + |
| *Neomicrorbis crenatostriatus* (Munster) | + | + | | | | | | | | | | + | | |
| *Neomicrorbis subrugosus* (Munster) | | | | | | | | | | | | | | + |
| *Proliserpula ampullacea* (Sowerby) | | + | | | | + | | | | | + | | | |
| *Pentaditrupa subtorquata* (Munster) | | | + | | + | | | | | + | | | | |
| *Eoplacostegus pusillus* (Sowerby) | | | | | | | | + | | | | | | |
| *Vermiliopsis fluctuata* (Sowerby) | | | | | | | | | + | | | | | |
| **Cirripedia** | | | | | | | | | | | | | | |
| *Brachylepas* sp | | | | + | | | | | | | | | | |
| *Brachylepas fallax* (Darwin) | | + | | | | | | | + | | | | | |
| *Calantica* sp? | | | | | | | + | | | | | | | |
| **Echinodermata** | | | | | | | | | | | | | | |
| *Austinocrinus* sp | + | + | + | | | | + | + | | | | + | | + |
| *Austinocrinus bicoronatus* (von Hagenow) | | | | + | | | | | | + | | | | |
| *Bourgueticrinus* sp | | | | + | | + | | | | | | + | + | |
| *Cidaris* sp | | + | + | + | + | + | | + | | + | + | + | | |
| *Galerites* sp | | | | | | | | + | | | + | | | |
| *Echinocorys* sp | + | | + | + | | + | | + | | + | | + | | + |
| *Micraster* sp | | | | | | | | + | | + | + | + | | |
| *Metopaster parkinsoni* (Forbes) | | | | | + | + | + | | | + | | | | |
| *Metopaster undulatus* Spencer | + | + | + | + | | | | | + | | | + | | + |



The photograph reproduced above was taken by a former member, the late Hallam Ashley, F.R.P.S. It shows an outcrop of Ostrea lunata chalk on the beach at Sandy Gulls, near Mundesley, Norfolk, on the 11th of April 1940.

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# PALAEOGEOGRAPHICAL MAPS OF THE SOUTHERN NORTH SEA BASIN: PLIOCENE (Coralline Crag) TO ANGLIAN (Lowestoft Till)

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## ABSTRACT

10 palaeogeographical maps representing successive stages in the evolution of the south North Sea Basin from the Coralline Crag to the Anglian glaciation are presented. They combine data from onshore and offshore, and from British, Netherlands and Belgian sources, adopting, for the most part, the stratigraphic correlations arrived at by the Anglo-Dutch Working Group, which met at Norwich in 1988.

Basic documentation is given.

## INTRODUCTION

Drawing palaeogeographical maps is an interesting exercise. Such maps are an attractive way to present the results of stratigraphical investigations. They can however never be entirely correct - only a synthesis of the latest data, and subject to change as the results of new investigations become available. Nevertheless they can also be a stern test of our ability to interpret current data, and often suggest fresh ways to investigate the stratigraphical record.

I was first attracted to problems of the palaeogeography of the southern North Sea basin (Funnell 1956) by the excellent maps produced by the Dutch Geological Survey (the Geologische Dienst, now the Rijks Geologische Dienst). In the 1970s and 1980s, however, a large number of new investigations were carried out, both beneath the southern North Sea and on the land areas of the Netherlands and eastern England. I made a first attempt to bring these results together in palaeogeographical form in my Introductory Lecture to the Annual Quaternary Research Association Field Meeting which assembled in Norwich in 1988. I revised the maps in the light of discussions of the Anglo-Dutch Working Group held at Norwich in 1988 (now published as Gibbard *et al.* 1991), and in their revised form they were included in my Introductory Lecture "Wiggles, Correlations and Palaeogeographies (3 million years of southern North Sea history)" given to the Cromer Symposium of the Society of European Quaternary Scientists, held at Norwich in 1990. In this paper I present the Maps with minimum documentation. Full documentation is being prepared for a later paper. Most sources are contained to in Gibbard *et al.* (1991).

## COMMENTARY

The ten maps which follow this text are all based on information obtained from the published literature. The main sources are indicated in the following commentary, but, as noted above, full documentation is still in preparation.

The least stable element in these reconstructions is the precise correlation in time of deposits across and within the southern North Sea. Basically I have taken the conclusions of the Anglo-Dutch Working Group (Gibbard *et al.* 1991) as the principal basis for correlation. They include several changes from previously generally accepted correlations. (Readers should note that not all of them have been fully incorporated into the documentation and figures in Gibbard *et al.* (1991).) The correlation of the mainly seismo-stratigraphically determined off-shore formations, in particular, cannot yet be regarded as satisfactorily resolved. The following notes endeavour to specify succinctly the basis on which individual maps have been compiled.

**Coralline Crag** (Fig. 1) Both marine faunas and pollen support correlations between the early Pliocene formations represented (Hodgson & Funnell 1987, Jenkins *et al*. 1988, Zagwijn 1979, 1989).

**Depo-centre** (Fig. 2) An original schematic representation of the present-day elevation (relative to sea-level) of the surface on which post-Coralline Crag deposits rest.

**Early Red Crag** (Fig. 3) Marine faunas and pollen support correlations between the Late Pliocene formations represented (Hunt 1989, Zagwijn 1974, 1986).

**Late Red Crag** (Fig. 4) If the Late Red Crag is Pre-Ludhamian and if the Pre-Ludhamian correlates with the Praetiglian (Gibbard *et al*. 1991), and if the offshore Ijmuiden Formation is Praetiglian (Zagwijn 1989) then this map correctly represents the Late Red Crag. (Most current literature however places the Ijmuiden and the majority of the underlying Westkapelle Formation in the post-Red Crag sequence.)

**Norwich Crag** (Fig. 5) Dutch formations and river flow directions (Zagwijn 1979, 1986); western North Sea facies and correlations (Cameron *et al*. 1984, 1987).

**Baventian** (Fig. 6) as for Fig. 5.

**Pastonian** (Fig. 7) Dutch formations and river flow directions as for Fig. 5; western North Sea facies (Cameron *et al*. 1987); Proto-Thames flow direction and elevations (Bridgland 1988, Rose 1989).

**Beestonian\Cromerian** (Fig. 8) as for Fig. 7. Thames flow direction and elevations (Bridgland 1988, Rose 1989); correlations with Rhine terraces (Urban 1982, Zagwijn 1986). Note: the Tiglian\Cromerian gap in the coastal U.K. succession is assumed to post-date the Beestonian.

**Cromerian** (Fig. 9) as for Fig. 8.

**Anglian** (Fig. 10) as for Fig. 9.

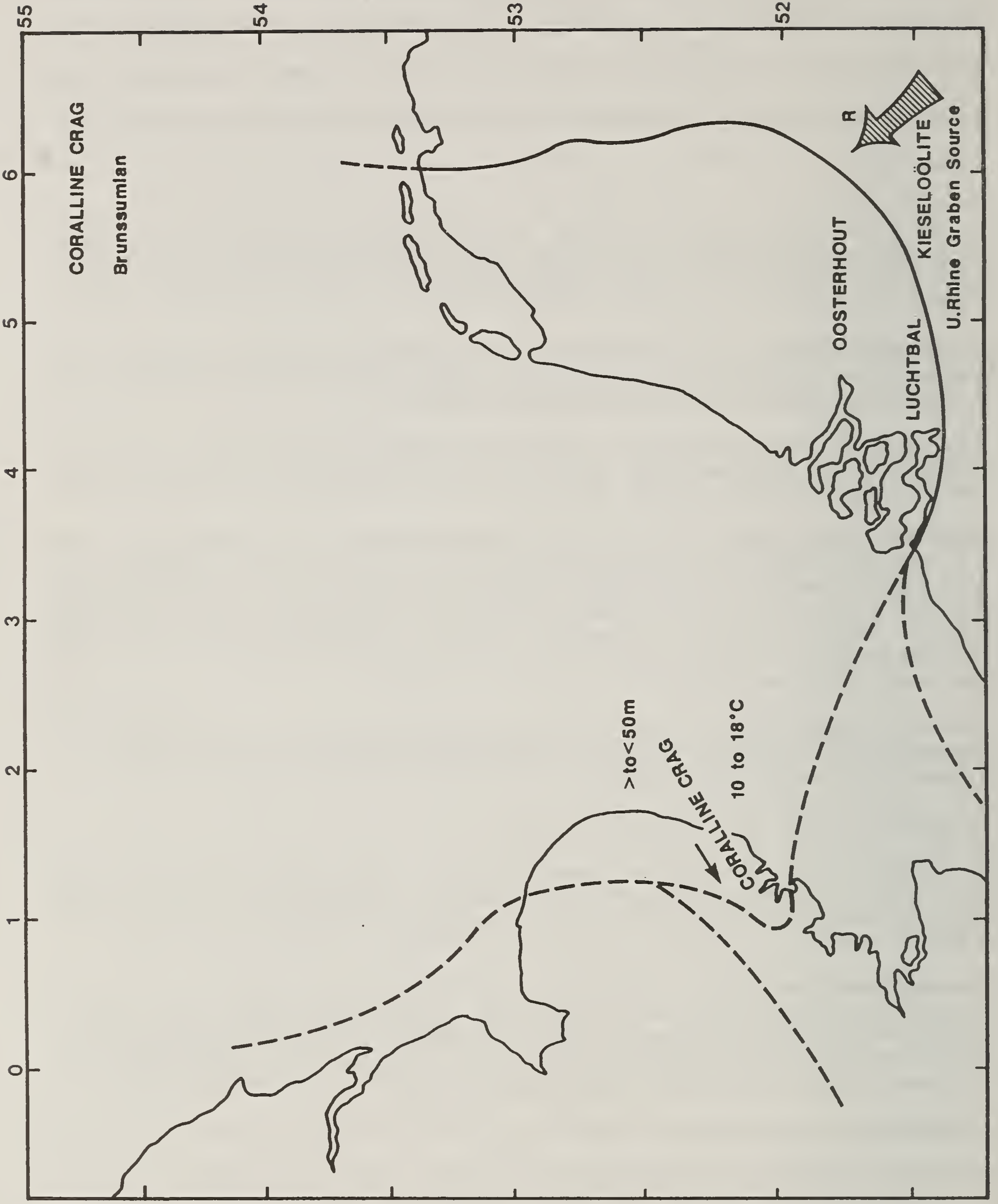

Fig. 1 Coralline Crag

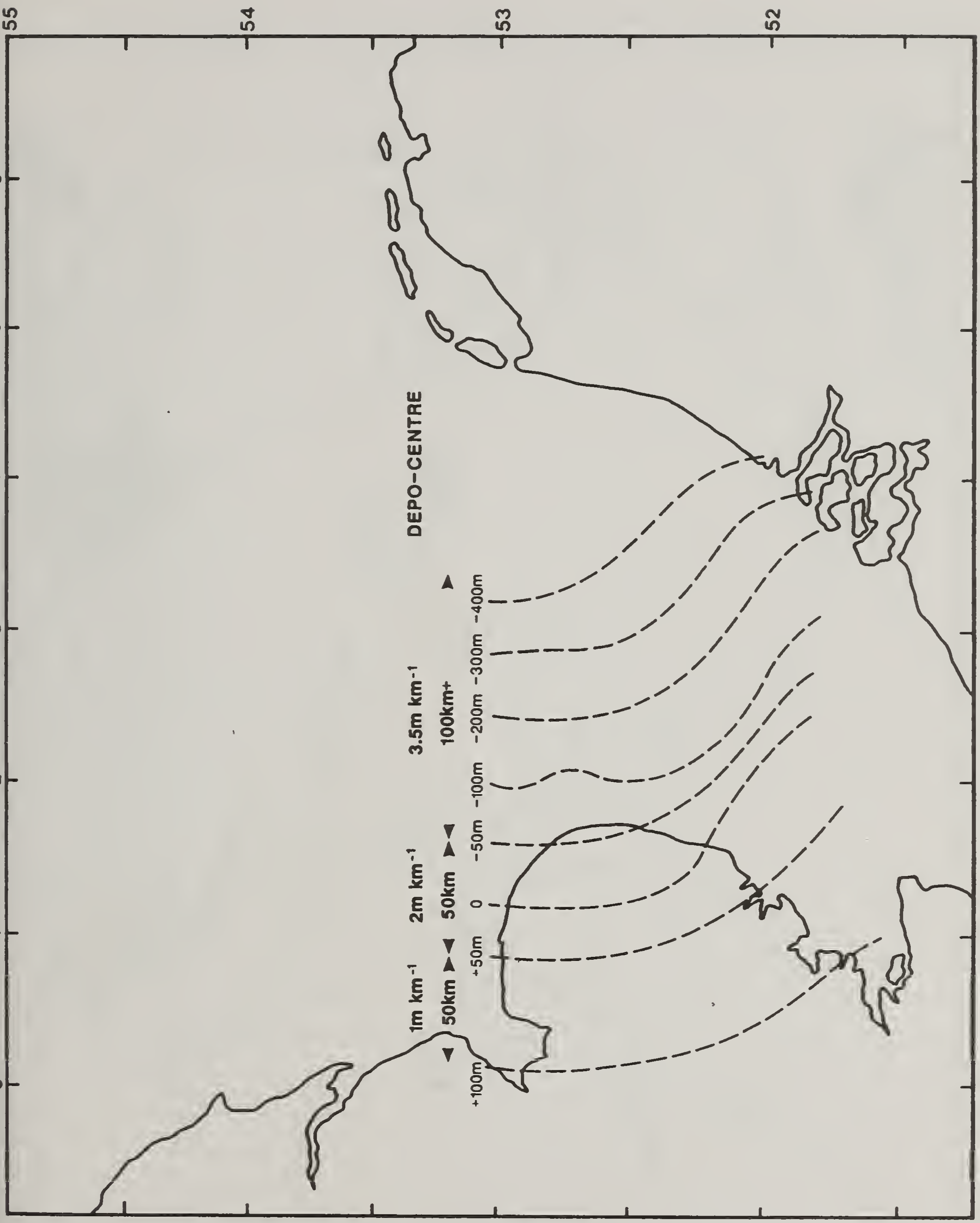

Fig. 2 Depo-centre

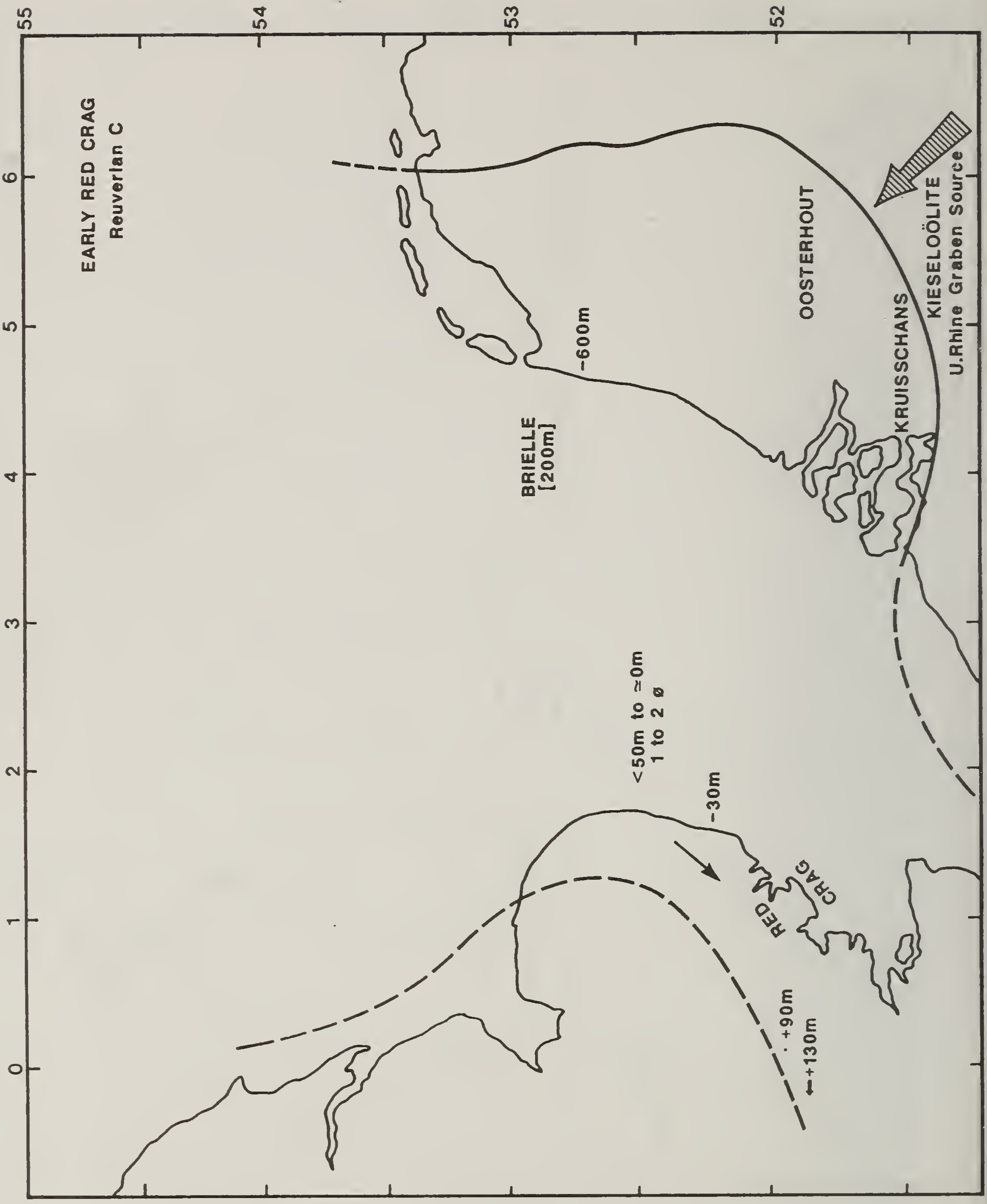

Fig. 3 Early Red Crag

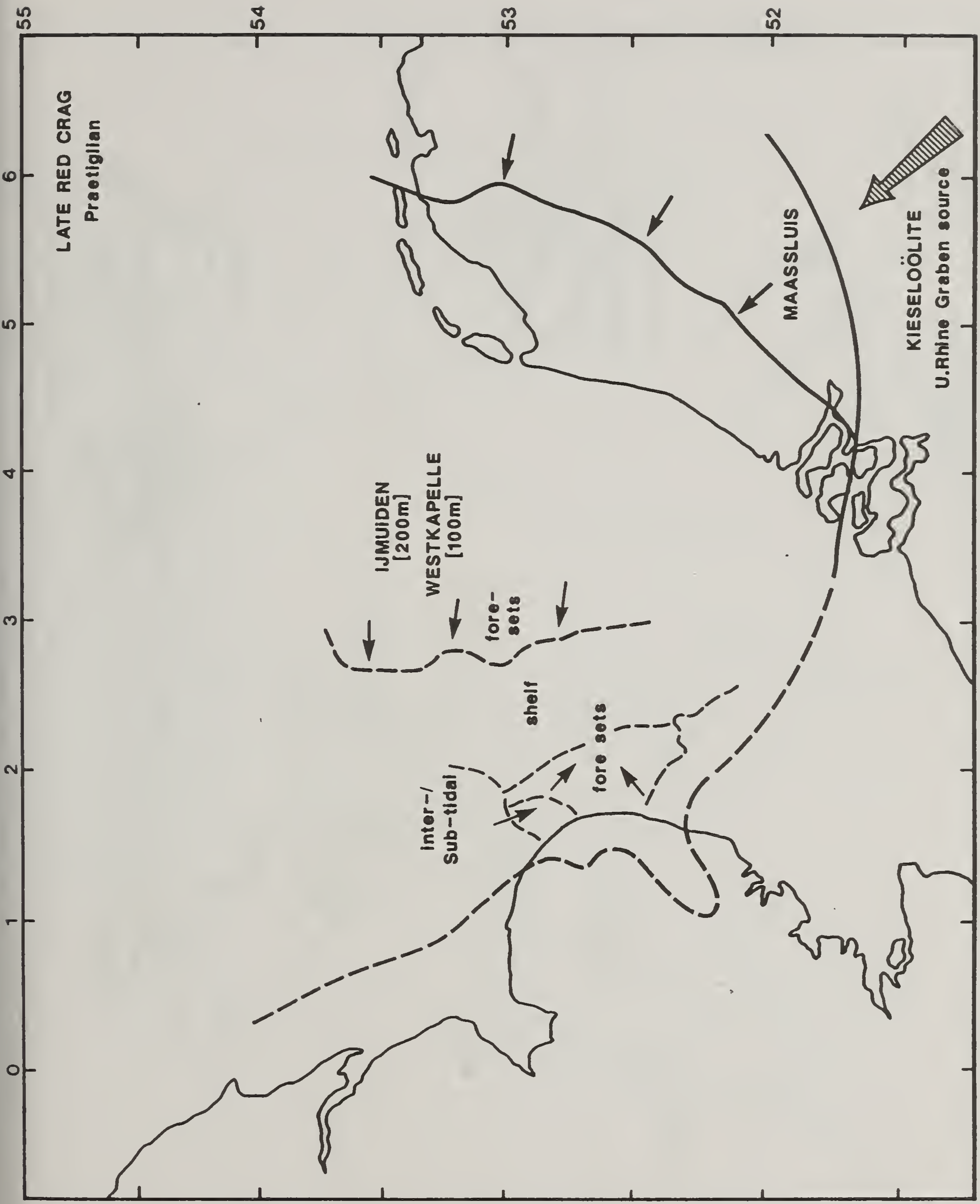

Fig. 4 Late Red Crag

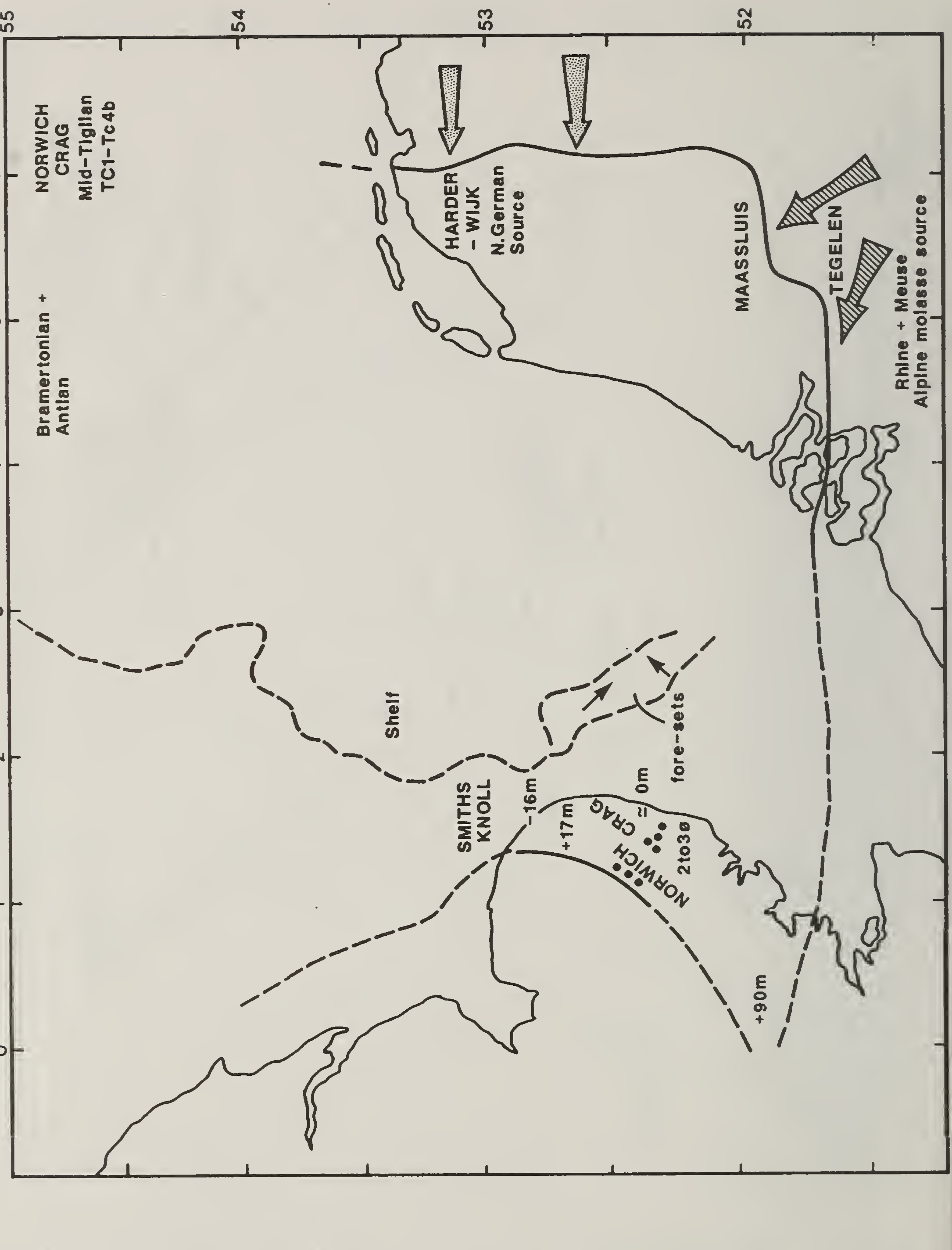

Fig. 5 Norwich Crag

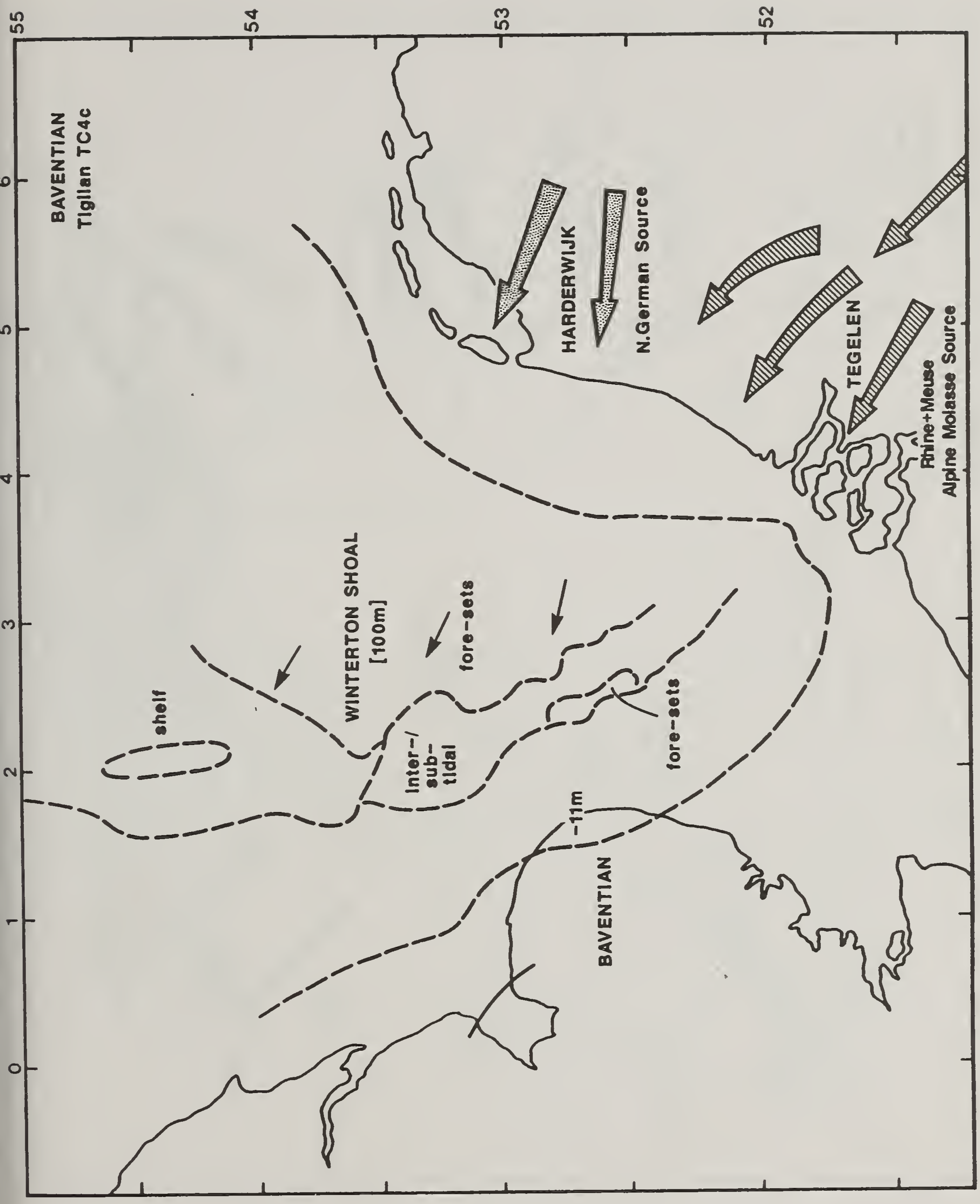

Fig. 6 Baventian

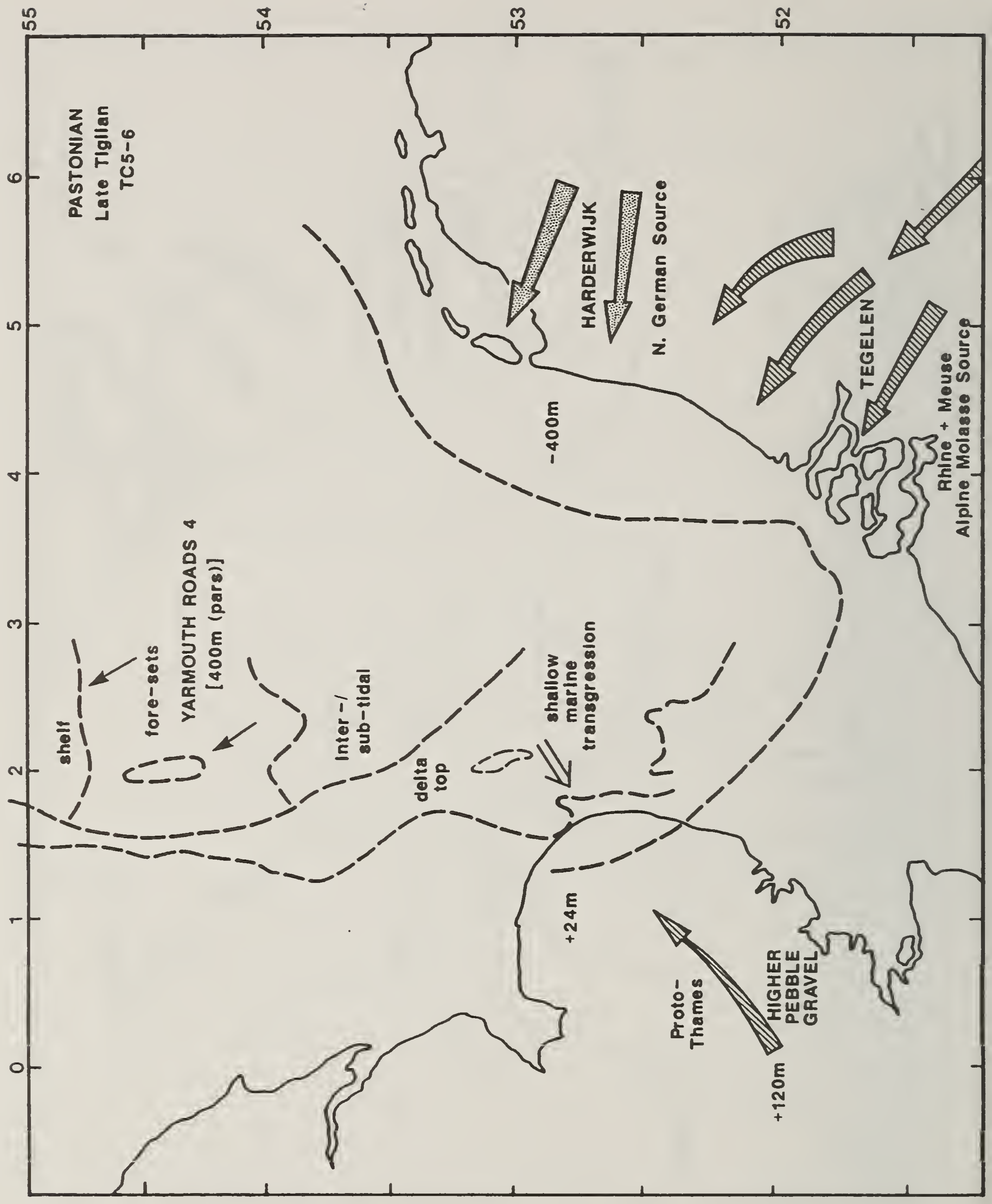

Fig. 7 Pastonian

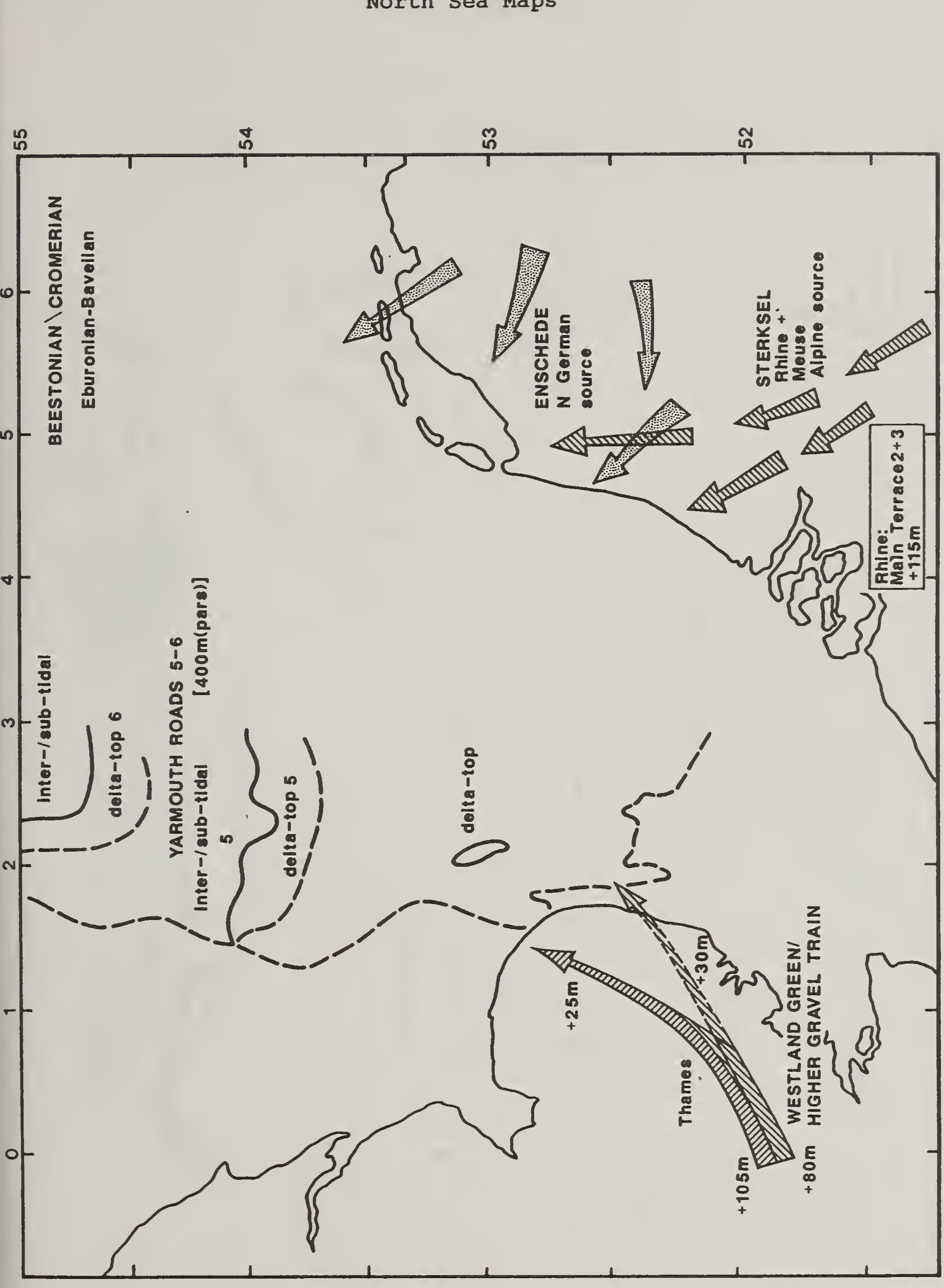

Fig. 8 Beestonian\Cromerian

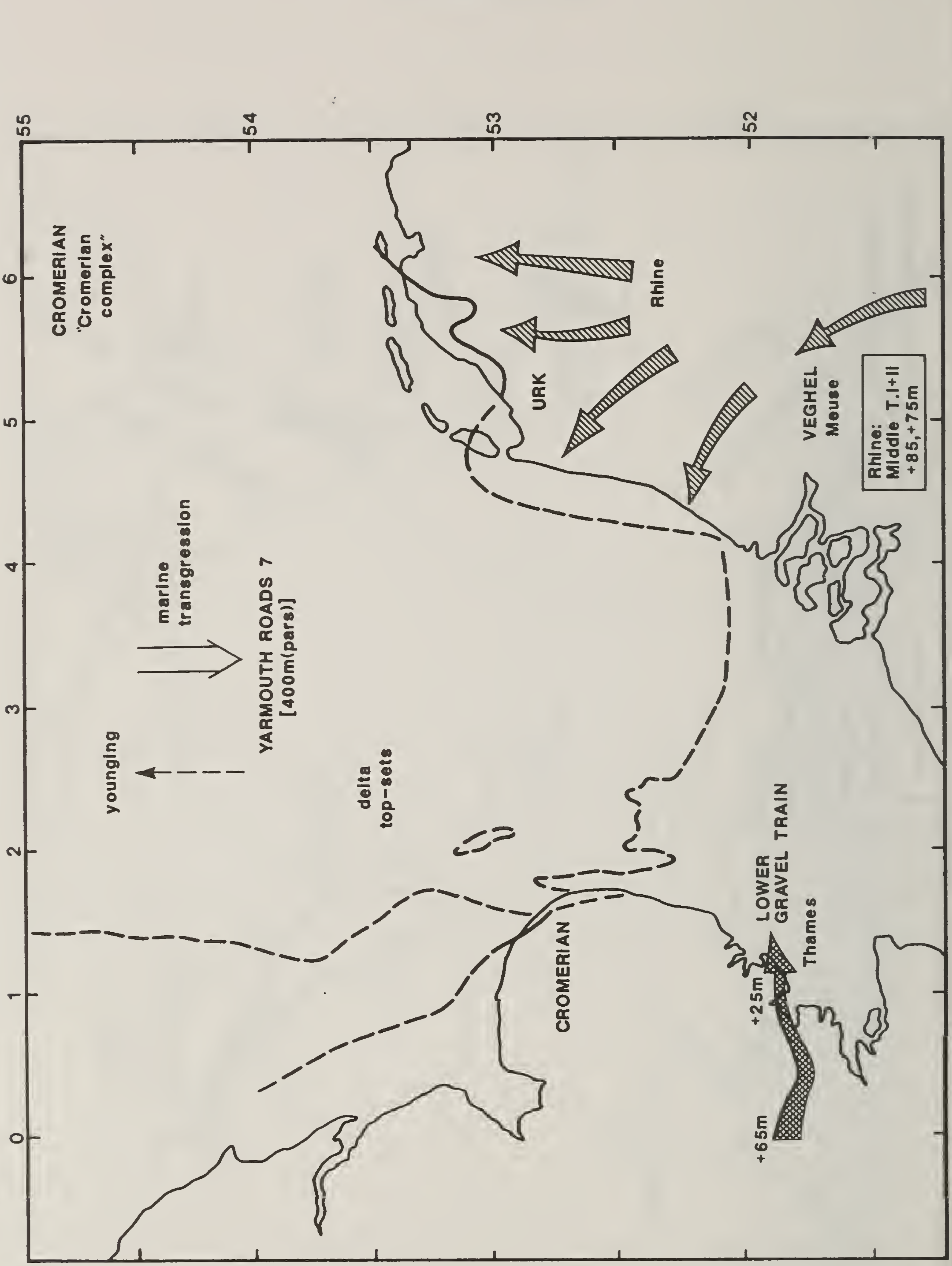

Fig. 9 Cromerian

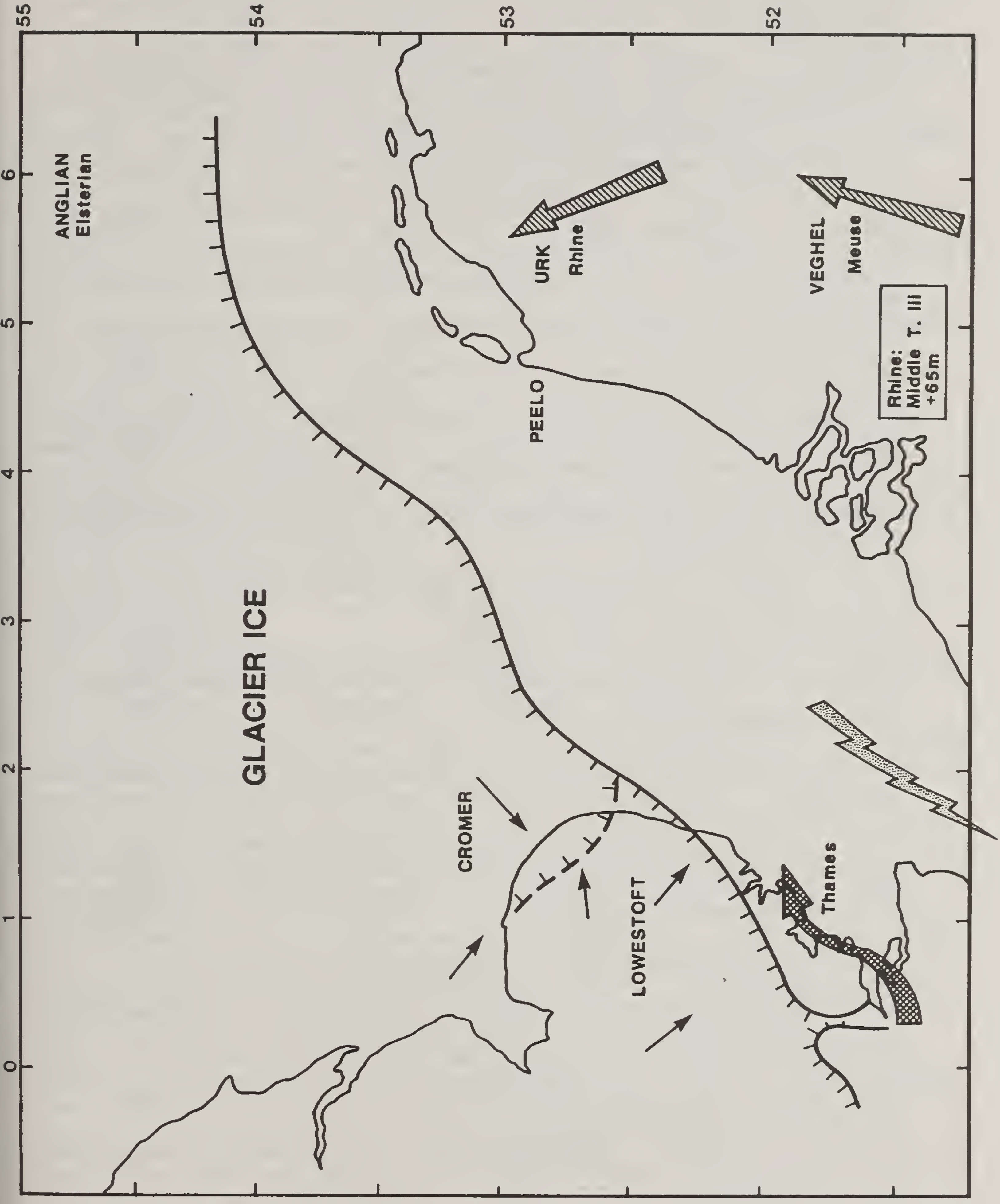

Fig. 10 Anglian

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# QUATERNARY DEPOSITS OF THE EASTERN WASH MARGIN

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## ABSTRACT

A full review of literature dealing with the Hunstanton Till of north west Norfolk, and associated deposits and geomorphic features is given. Correlations are discussed with other regional deposits and pointers are provided for possible future research on the glacial stratigraphy of north west Norfolk. For the first time all the available published work on this important deposit is brought together.

## INTRODUCTION

In the main this article will be a detailed review of papers that refer to the Hunstanton Till (also variously named the Hunstanton Boulder Clay, Brown Boulder Clay and Hessle Boulder Clay). An exhaustive search of all relevant references has been undertaken to provide a historical and broad analysis of research undertaken on this deposit. All the available information has been considered, irrespective of the scientific approach or contemporary conceptual framework, in order that valuable historical observations recorded in old papers are not omitted.

Glacial deposits are laterally variable in both their lithology and thickness. The sequence of deposits relating to the Hunstanton advance are no exception. They show a possible relict distribution with deposits and associated erosional features being generally restricted to levels below 30m O.D. (100 feet, Straw 1960).

The first reference to the diamicton is Rose (1835) who described a section at Hunstanton cliff containing '9.5 feet of sandy loam with small angular fragments of flint' (page 200). Rose considered the lithology to overlie an ancient beach deposit and to be of a diluvial origin.

Subsequently Seeley described the deposit in 1866 and alluded to a glacial origin but concluded that the deposit was 'deposited by drifting ice...............no evidence in the deposit for glacier action' (page 479). Woodward (1883) also proposed a paratill origin; 'whilst shore-ice, laden with fragments of the rocks derived from the beaches around Lincolnshire and Yorkshire, floated down with the tide, and deposited its burden on the spot' (page 101).

Whitaker (1883) refers to a 'Boulder Clay......of a reddish colour' (page 135) at Hunstanton. The till is then further described and recognised as a "true" glacial deposit with associated sand and gravel by Whitaker and Jukes-Browne (1899).

Madgett and Catt (1978) concluded that the Hunstanton Till is the weathered relict of a southern extension of the Skipsea Till and proposed that the term Hunstanton Till should be abolished. It is our opinion that since the Hunstanton Till unit is distinct from the Lincolnshire and Yorkshire sequences, then the term Hunstanton Till should remain. Straw (in discussion of Madgett and Catt 1978) also suggests that it would be 'premature' (page 101) to replace the term Hunstanton Till.

The authors are of the opinion that the Hunstanton Till should not be assigned to any Stage of the Quaternary prior to the availability of any definite chronostratigraphic or biostratigraphic evidence. It is recognised, however, that virtually all workers have assigned a Devensian - Weischelian - last glacial - age to the 'Hunstanton' deposits and therefore when considering past papers the original authors correlations are used. Where no direct correlation has been previously used, the term 'Hunstanton Glacial episode' or 'Hunstanton Glaciation' has been used in preference to any accepted stage name of the Pleistocene, for the period of time in which the Hunstanton Till, its associated glaciofluvial deposits and geomorphic features were emplaced.

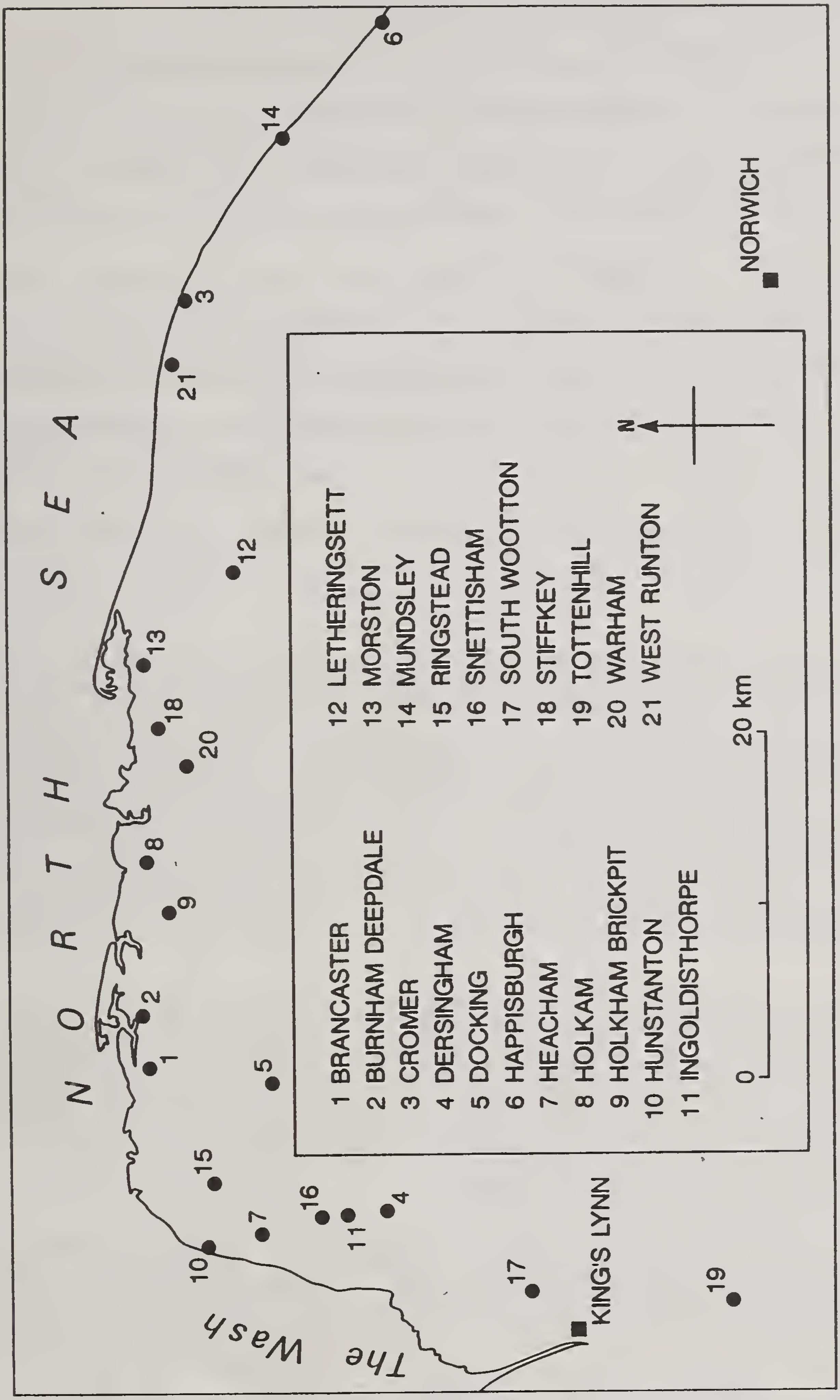


FIG. 1: LOCATION MAP

Fig. 1

## LITHOLOGICAL DESCRIPTION OF THE HUNSTANTON TILL

The Hunstanton Till unit has been qualitatively described by many authors. Descriptions are generally void of numerical information; clast lithological analysis, for example, is often limited to a record of interesting or easily identifiable lithologies. A description of erratic material, although interesting, gives a bias to any analysis. A study of four different sites, two kamiform deposits in the Heacham Valley (TF 699371, TF 692366), the Hunstanton Esker (TF 697405), and one till site in Heacham (TF 672377) ) in west Norfolk have recorded a maximum of only 5.2% far travelled material with an average of 4.4%.

Whitaker and Jukes-Browne (1899) provide a description of the till as having a reddish-brown colour with grey streaks passing into a brown sandy unit at times, with fewer stones than the chalky till of the region. Erratics recorded include basalt, quartzite, and red and yellow sandstones. Cameron, in the same memoir (Whitaker and Jukes-Browne 1899), refers to 'seams or "flashes" of gravel' (page 87) within the Till at Burnham and at the southern end of Hunstanton Cliffs (TF 673413). At the latter location the Till was observed to be very gravelly at its base. A section in the Cliff Gardens (TF 673413) showed approximately 2.5m of till, and 2.5m of sand, interdigitated at one point.

Reid Moir (1930 and 1931) leans heavily on the description provided by Whitaker and Jukes-Browne in the 1899 memoir to the Wash borders. He collected, however, a number of erratics from the Till which were identified as diorite, pegmatite, quartz porphyry, dolerite, chert, quartzite and schist and concluded that the derivation was from the north and north east. Reid Moir also noted that the Till often assumes the texture of a gravelly loam near the surface.

Solomon (1932) observes the lack of chalk clasts in the Till, and collected erratic clasts of dolerite, dark blue greywacke and Cheviot porphyrites He also examined the heavy mineral assemblage, concluding the Till was rich in limonite and other unspecified iron minerals. Pink garnets were the commonest non-opaque mineral and tourmaline, amphiboles and epidote were present. He noted that a distinctive feature of the Till was the presence of augite.

Baden-Powell (1944) describes the Till as reddish-brown, sometimes with a purple tinge and with a grey mottled colouration along its vertical joints. It contains fragments of the underlying 'marine sands' at Hunstanton and chalky till at Holkham. He also describes a wide range of erratic material; Jurassic oolite and limestone, and pre-Jurassic sandstone, quartzite, granite, basalt, schist, gneiss and quartz porphyry. He also noted that the Till is hard and reddish-brown when unweathered and soft and grey when weathered (page 207).

Suggate and West (1959) described the 'Hessle' of Lincolnshire and the 'Hunstanton Brown Boulder Clay' as being; 'reddish-brown sandy clay with abundant small fragments, notably of chalk, flint and coal; stones over 3 inches in size are relatively uncommon. In many exposures ashen-grey partings are characteristic. The variations in colour and texture are no more than are to be expected in a single extensive sheet of boulder clay' (page 280).

Straw (1960) also provides a full account of the lithology. The Till is described as red-brown or grey-brown in colour, sandy or loamy in texture containing numerous and varied erratics (including Cheviot lithologies). Erratic content is variable, occasionally being absent.

Madgett (1975 (page 105) ) described the Till as being reddish-brown in colour (5YR 4/4 Munsell Soil Color Chart).

Evans (1976) sampled the Hunstanton Till at the gas-works site, Hunstanton (TF 672402) and noted its texture to be a sandy clay with an increasing silt component with depth. A high percentage of angular clasts was present together with well rounded rotten chalk. Compared to till samples removed from the Hunstanton esker (TF 6940) the gas-works diamicton was clay deficient. Evans attributes this to weathering and considers the Till at the esker to possess textures indicative of flow till with a sand content greater than 67%.

Gallois (1978) describes the Till as a dull reddish-brown sandy clay, its colour being derived from Triassic marls. Local chalk and flint dominate the clast content. Exotic lithologies include Bunter, Carboniferous sandstone and coal. Whin Sill dolerite and rhomb porphyry are amongst the igneous suite together with schistose and gneissic metamorphic rocks. Provenance is thought to be the east coast of northern England and southern Scotland with the rhomb porphyry being derived from Norway. He also describes a possible Hunstanton Till relict at Tottenhill Gravel Pits where a 'cryoturbated dull brown and reddish-brown, sparsely stony, sandy clay and clayey sand' was excavated (Gallois 1978, page 27). A quartz porphyry pebble was also found at Tottenhill which Gallois claims is indicative of the Hunstanton Till.

Madgett and Catt (1978) undertook a detailed qualitative and quantitative analysis of the till sequences of Lincolnshire and north Norfolk. They provided the first rigorous and detailed study of the Till and their work is worth detailing here. The major conclusion to be drawn concerned the tills from Lincolnshire where the diamictons are renamed Skipsea (formerly the Drab) and Withernsea (formerly the Purple) Tills. The 'Hessle Till' is simply regarded as a weathered profile of these Tills and therefore on mineralogical criteria the Hunstanton Till of north Norfolk is a weathered variation of the Skipsea Till. They further note that 'the weathering of the Tills involves decalcification, the softening and dissagregation of sandstone, shale, igneous and metamorphic erratics, clay alteration and translocation, and the alteration of micas and some heavy minerals in the sand and silt fractions' (Madgett and Catt 1978, page 55).

Particle size results show that silt was present in significant amounts ranging from 27% to 38%. The amount of chalk and flint is greater than in the Tills north of the Wash. Till sampled at Stiffkey (TF 973431) had 73.6% chalk and flint in the 6 - 16mm size range whereas a sample from North Reston, Lincolnshire (TF 382838) contained 37.1% (Madgett and Catt 1978, page 70). They consider these two samples to be decalcified and that the percentage of chalk and flint would have been higher prior to weathering. Additional sand lenses were noted in the middle of the section at Holkham Brickpit (TF 863428) and are considered to be due to reworking or melt-water washing of the Till during glacial melting. Frost cracking of the chalk erratics has produced irregularly shaped fragments which are being attacked by acid groundwaters (page 89).

'Reddish-brown colours, previously regarded as characteristic of the 'Hessle Till', result from oxidation of pyrite and siderite to depths of approximately 5m' (Madgett and Catt 1978, page 55). Of particular interest to this paper is the study of the 'soil profile' at Holkham Brickpit (TF 863428) and of a number of till samples from north Norfolk (precise location not provided). Although the Hunstanton Till has long been described initially by its colour, the authors point to the risk this brings for accurate correlation. Colours in the Till are variable, particularly near the surface, and probably reflect weathering stages as well as primary differences. For example, brown (7.5YR 4/2) till near the surface and reddish brown colours (5YR 4/4) at depth is observed at Holkham.

The fact that pyrite and siderite are either absent or rare in north Norfolk suggested to Madgett and Catt that the Till in north Norfolk is chemically and bio-chemically weathered throughout its depth. The hydrated iron oxides that result provide the Hunstanton Till with its characteristic reddish-brown colour. Grey vertical partings are observed in the Till and are due to 'gleyed surfaces of prismatic soil structural units' (Madgett and Catt 1978, page 89). These fissures are associated with waterlogging and chemical weathering which turns the ferric compounds to ferrous producing a colour change from red-brown to grey.

A lack of easily weathered minerals such as calcic plagioclase, mica, chlorite, chamosite and siderite is noted towards the top of the Holkham section. The till at Holkham is considered by Madgett and Catt (1978) to be enriched in fine clay throughout its thickness but the clay content is observed to increase upwards although depleted in the top 0.36m (probably as a result of soil translocation). It is considered that the clay fraction is a result of the weathering of micas, with subsidiary amounts of chamosite, apatite, chlorite, pyroxine and collophane.

Balson and Cameron (1985) identify an offshore unit, the Bolders Bank Formation which they describe as a 'brown sandy clay with 5 to 10% lithic granules, mainly of Upper Cretaceous, Jurassic and Permo-Triassic sedimentary rocks' and 'minor igneous and metamorphic components of probable Scottish or Scandanavian origin' (page 236).

Work by Gale, Hoare, Hunt and Pye (1988) on the Pleistocene sequence at Morston (TF 896436), has revealed 'the first site in East Anglia at which till of presumed last glacial age has been found overlying older till' and where 'interglacial deposits have been found between glacigenic sediments' (page 532). Gale et al. noted a more complex sequence than Solomon (1931, 1932). Morston is now a very important site for elucidating Middle and Late Quaternary deposits, for here a complex sequence of interglacial beach deposits overlies a highly calcareous till and underlies a diamicton equated with the Hunstanton Till.

The basal unit described by Gale et al. (1988) is a 'white, highly calcareous' (96.4%) 'gravelly mud' (page 525) and the presence of Jurassic to Quaternary microfossils strongly suggests the sediment to be a till.
Overlying the till are sands with sedimentary structures indicative of beach deposits and particle textures indicating a previous glacial existence. A laminated mud within the sand contains pollen suggesting a temperate (mixed oak forest) climate.
Above the sands are imbricated matrix-supported gravels which are the units regarded by previous workers as being beach gravels. Gale et al. (1988) do not preclude such a origin although note that such textures are not common in beach environments. The upper surface of the gravels is at 5.03m O.D. indicating sea levels similar to those of today.

The upper sediments are described as 'very or extremely poorly-sorted, and to be composed of gravel supported within a matrix of muddy sand and sandy mud' (page 530). The presence of igneous exotics allows the authors to conclude that they are dealing with a till. Evidence in the form of matrix supported pebbles suggests re-working of some of the material by slope processes prior to weathering of the section. It is considered that the whole of the till unit is heavily weathered since it is decalcified.

## PUBLISHED DEPOSITIONAL MODELS PROPOSED FOR THE HUNSTANTON ICE-SHEET

Solomon (1932) noted that the 'Brown Boulder Clay.........is the product of a feeble ice sheet' (page 269).

Boulton et al. (1977) proposed a model of the late Devensian ice sheet where the Hunstanton phase of the glaciation was considered to be a surge event. It is suggested that the event occurred as a result of an ice margin instability caused by an unknown mechanism. They suggest that high glacier velocities are indicated by the lack of drumlinoid forms along the east coast. Straw (1979) supported the surge hypothesis on the basis of the low gradient of 1:750 for the surface profile of the ice sheet.

If the ice surge model for the glacial episode that deposited the Hunstanton Till is a correct one, then much work is needed to relate it to recent surge deposits (Sharp 1985) and to compare them to observed sequences in north west Norfolk. Sharp (1985) has noted that at the distal margin of surging glaciers, basal debris which has been thrust to a supraglacial position is deposited by meltout and sediment flows. Fluted lodgement tills were seen at Eyjabakkajökull with glaciotectonic structures and strongly orientated pebble fabric. Observations and analysis of the till lithology, structure and fabric at one continous exposure at Heacham (TF 672369), and therefore close to the assumed ice margin, suggests that lodgement till is present but that the pebble fabric is not well defined and that no subglacial deformation is present. Incompetent bed material causes glaciers to spread out under their own mass (Rose 1989). This would account for the observed low surface gradient and the apparent absence of glacial erosion of the underlying sediments (Rose 1989). A similar lack of erosion is noted for sediments underlying the Hunstanton Till at Morston (Gale et al. 1988).

## FABRIC ANALYSIS OF THE HUNSTANTON TILL

West and Donner (1956), in one of the first statistical treatments of till fabric, considered the orientation of till pebbles throughout eastern England. Holkham Brickpit (TF 863428) was the only site considered in the Hunstanton Till where a 2m section was exposed. A preferred pebble orientation of 340° was established, (West and Donners 1956, page 81 Fig. 4) indicating flow from the north north west.

Suggate and West (1959 page 268, Fig 1) show two arrows providing a direction of preferred stone orientation in the 'Hessle Boulder Clay'. One of the arrows is situated in the village of Heacham (TF 6737) indicating a direction of approximately 116°. The second analysis appears to have been undertaken at Holkham and a direction of approximately 162° is indicated. Unfortunately the text does not support the analyses with details of method or interpretation. This is unfortunate bearing in mind the analysis of West and Donner (1956) which provides a 340° orientation, 180° different from the Suggate and West (1959) paper. This perhaps indicates a different recording technique for the two studies, both of which indicate a N.N.W. - S.S.E. trend.

## THICKNESS OF THE HUNSTANTON TILL

The thickness of the Till is variable. Sections described by Reid Moir in 1930 include 3m of till at the approximate position of the Hunstanton Oasis (TF 671407), 1.5m in the pit north-west of the gas-works (TF 672400) and approximately 3m at Old Hunstanton Cliffs (TF 681425). Whitaker and Jukes-Browne (1899) record 3m to 6m at the southern end of Hunstanton Cliffs (TF 673413), while Gallois (1978) considers the Till to be less than 10m thick (page 18).

## BASAL BOUNDARIES OF THE HUNSTANTON TILL

In the Memoir of 1899 Whitaker and Jukes-Browne describe a brief reference to a pit a mile south of Burnham Deepdale showing boulder clay, red in its upper part and white below. The inference was made that there is superposition of two till lithologies. Further sections at Burnham are also noted where the Till overlies a very chalky fine gravel and sand; the nature of the contact was not seen. Unfortunately no detail of these sections are now available.

Reid Moir (1930) described sections where Till overlies, and is banked up against Chalk at Old Hunstanton cliffs, and underlain by glaciofluvial gravel and sand at a pit to the north west of the gas-works site (TF 672403).

Solomon (1932) noted a 'shingle beach' underlying the Till to the west of Morston. Baden-Powell and West (1960), observed at Stiffkey (TF 991442) the Hunstanton Till overlying a 'rounded flint shingle' which they presumed to be Solomon's beach gravel (page 78).

Straw (1960) claims that nowhere does the Hunstanton Till come into contact with the widespread chalky till. Onshore the Hunstanton Till is located at lower elevation, below approximately 30m, whereas the chalky till extends through a wider elevation range to higher levels.

Evans (1976) noted in a small section near Hunstanton gas-works site that till overlies basal yellow-brown, well bedded sands with mica flakes and lenticles of chalk and carbon. Evans also noted small channels with small scale cross bedding in these sands. The contact between the till and the sands was sharp.

Investigations for the Wash Water Storage Scheme (Gallois 1979) showed chalky till present in the Wash in places occupying glacial scour hollows and buried valleys and noted that the relationship between the chalky and Hunstanton Tills 'cannot be directly determined' (page 25). However, boreholes undertaken in the Wash (Appendix A to Gallois 1979, pages 66 and 67) have provided interesting sequences which perhaps require some further investigation. Hunstanton Till has been found above grey sandy clay with traces of organic matter which is postulated as being till or interglacial deposits (Borehole WY 208: near Hull Sand, TF 5545 2921), above dull red-brown varved clays and resting directly on Lower Kimmeridge Clay (Borehole WY510: near Daseley's Sand, TF 5698 3055). In the River Great Ouse (Borehole WY 1004, TF 6069 2220) a borehole was sunk where 7.35m. of till was encounted. The upper portion being possibly Hunstanton Till passing down into a chalky facies. Another borehole (WY1509) near the Bulldog Sand (TF 6131 2947) proved approximately 1.1m of Hunstanton Till directly overlying 1.5m of chalky till. In the event of conclusions being drawn on the superposition of these deposits Gallois, in an earlier article (1978), does note that locally the Hunstanton Till is very rich in Cretaceous material making it difficult at certain locations to distinguish it from chalky till.

Balson and Cameron (1985) indicate that offshore the Bolders Bank Formation 'has a flat or gently undulating base, rests on bedrock or locally on Hoxnian sediments in the west, and overlies Ipswichian marine sediments to the east of $2^{o}$ east' (page 237).

The presence of Holocene sediments at Holkham (TF 8944) resting directly on chalk, (Funnell and Pearson 1989), support Straw (1960) who showed that Hunstanton Till is absent between a point 1 km east of Marsh House Farm (TF 863443) and Stiffkey (TF 9944) a distance of some 12 to 13 km.

## UPPER BOUNDARIES OF THE HUNSTANTON TILL

Upper boundaries of the Till are variable, and frequently show soil development (Madgett and Catt (1978), J. Wymer (pers comm 1990)).

The Till was seen below blown sand at Old Hunstanton and south of Hunstanton (Reid Moir 1930) and below the 'submerged forest' at Brancaster (TF 760452) (Reid in Whitaker and Jukes-Browne 1899): re-worked till below yellow mica rich sands and units of granular chalk and carstone pellets north west of Neats Ling, (TF 720392) (Evans 1976) and below yellow sands near Hunstanton Hall (TF 692419) (Evans 1976).

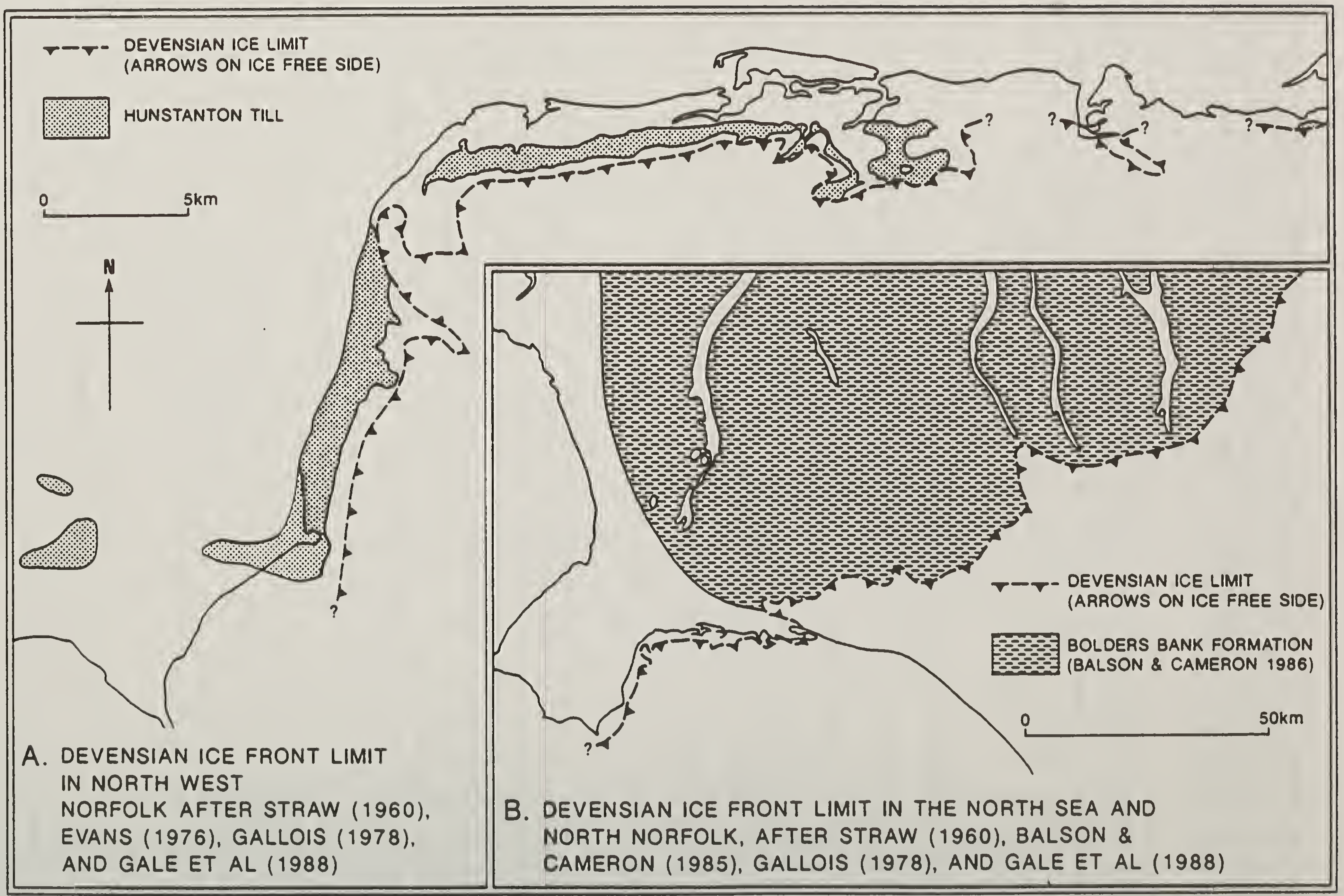
A 14C date of 8410 + 50 B.P. (SRR 2389) was obtained from peat immediately overlying the glaciofluvial sand at Brancaster (TF 773446) (Funnell and Pearson 1989). Evidence from Lincolnshire, however, (see elsewhere in this paper) suggests that deglaciation had occurred much earlier than this date. An unspecified palaeosol on the upper surface of the till has been recorded by J. Wymer (pers. comm. 1990) at Titchwell.

## REGIONAL EXTENT OF THE HUNSTANTON TILL

The presence of Hunstanton Till between Heacham and Morston has long been recognised. The extent to which the Till is distributed beyond these western/southern and eastern limits has been the subject of much discussion. The distrbution of Till seems to be closely controlled by the topography, and it is not observed higher than the 30m contour (Fig. 2).

One of the earliest attempts to define the regional extent of the Hunstanton Till was Solomon (1932) who proposed an ice limit from Hunstanton to Stiffkey. Solomon (1932) observed a 'sandy brickearth' as far east as West Runton (TG 185433) and Mundesley (TG 315367) which he regarded as being part of the 'Little Eastern' glaciation and not equivalent to the Hunstanton glacial episode. Baden-Powell (1944), however, considered the sandy brickearths to be stratigraphically equivalent to the Hunstanton Till.

Baden-Powell and Reid Moir (1944) suggested, on the basis of lithological similarity, the presence of Hunstanton Till at Happisburgh (TG 384313) thereby extending the eastern limit of the Till by 40km further than the previously recognised most easterly outcrop on the north Norfolk coast. Baden-Powell admitted the Hunstanton erratic suite to be absent or at best rare in the Happisburgh deposit, but he still claimed it to be stratigraphically equivalent to the Hunstanton Till. Suggate and West (1959), on the grounds of lithological inconsistency with the Hunstanton Till elsewhere in north Norfolk, rejected the Happisburgh deposit as being Hunstanton Till. Straw (1960) considered the Happisburgh deposit to be gelifluctate derived from stratigraphically older lithologies. A poorly described section at Letheringsett (TG 044385) was considered to contain deposits correlative to the Hunstanton Till (Baden-Powell and Reid Moir 1944).


DEVENSIAN ICE LIMIT (ARROWS ON ICE FREE SIDE)
HUNSTANTON TILL
0 5km
N
?
DEVENSIAN ICE LIMIT (ARROWS ON ICE FREE SIDE)
BOLDERS BANK FORMATION (BALSON & CAMERON 1986)
0 50km

A. DEVENSIAN ICE FRONT LIMIT IN NORTH WEST NORFOLK AFTER STRAW (1960), EVANS (1976), GALLOIS (1978), AND GALE ET AL (1988)

B. DEVENSIAN ICE FRONT LIMIT IN THE NORTH SEA AND NORTH NORFOLK, AFTER STRAW (1960), BALSON & CAMERON (1985), GALLOIS (1978), AND GALE ET AL (1988)

Fig. 2: EXTENT OF THE HUNSTANTON TILL AND BOLDERS BANK FORMATION IN THE NORTH SEA AND NORTH WEST NORFOLK WITH POSTULATED ICE FRONT MAXIMA

Fig. 2

Funnell and Pearson (1989) note that at Cley Eye (TG 052451) till underlies salt marsh deposits. The till is not, however, of the 'Hunstanton' facies (Funnell pers. comm. 1990) but is of chalky till and therefore it is likely that the 'Hunstanton' ice advance did not extend further than Stiffkey (TF 990442). There is no credible reason to accept that the Happisburgh or Letheringsett deposits of Baden-Powell and Reid Moir (1944) are part of the Hunstanton glacigenic suite of sediments.

Interestingly, Farrington and Mitchell (1951), having visited the north Norfolk coast, concluded that the last glaciation did not extend further south than Flamborough Head (TA 258708) in east Yorkshire and further stated that the Cromer Ridge in north Norfolk could well be associated with the Hunstanton Till. No evidence has been brought forward to support these views.

Suggate and West (1959) concluded that the 'Last Glaciation extended south through Holderness and east Lincolnshire to the north Norfolk coast' (page 281). They further suggested that an ice lobe advanced into the Wash. The maximum height obtained in north Norfolk was 30m O.D.

Straw (1960) mapped the regional extent of the Hunstanton Till by reference to the outcrop of the Till, to the presence of characteristic erratics, surface soils and the recognition of glaciofluvial landforms. Straw defines the easterly limit of the Till near the mouth of the River Stiffkey (TF 990442). Straw agrees with the height limit, as suggested by Suggate and West (1959) of 30m O.D., but further noted that near Brancaster the characteristic erratics occur up to 36.5m O.D.

Evans (1976) determined the extent of glacial advance by plotting the distribution of till, the limit of the Hunstanton esker and a series of deep cuts on the west facing slopes of Sandringham Warren which he regarded as sub-glacial channels. (TF 6728). The latter features extend the limit of the 'Hunstanton' advance further south than suggested by Straw (1960).

Gallois (1978) noted a till at Tottenhill (TF 632116) which he suggests is equivalent to the Hunstanton Till, previously unrecognised south of King's Lynn. A distribution of Hunstanton Till in the Wash is recognised (Gallois 1979). (Fig. 2.)

The British Geological Survey in mapping the offshore Quaternary deposits between 1979 and 1983 (Balson and Cameron 1985) provided a more complete record than the comparable onshore time equivalent sequences. The extensive Devensian unit, the Bolders Bank Formation is described elsewhere in this paper. A borehole taken east of Lincolnshire (53° 32′ N , 0° 44 3′ E) penetrated some 12m of an assumed Devensian till. A number of sub-glacial valleys of general orientation N.N.W. - S.S.E. have been identified; they are infilled by assumed Devensian glaciofluvial and glaciolacustrine sediment.

Funnell and Pearson (1989) in investigating Holocene sediments on the north Norfolk coast penetrated the Hunstanton Till at a number of locations. At Holme Next The Sea (TF 7043) the Holocene sediments were seen to lie in a shallow trough striking approximately east-west; parallel to the presumed ice front (Fig. 2). Six to seven kilometres to the east at Brancaster (TF 7744) undated glaciofluvial sands have a surface dip to the north. Hunstanton Till was noted by J Wymer (in Funnell and Pearson 1989) on the foreshore at Titchwell (TF 7545). This suggests that the shallow trough continues eastwards.

## GEOLOGICAL AGE AND CORRELATION

### INTRODUCTION

Glacial deposits are often dissected and laterally impersistent; the Hunstanton Till is no exception. Traditionally the stratigraphic succession used in Great Britain has relied heavily on biostratigraphy based on pollen assemblage biozones. The Hunstanton deposits are geographically isolated from any of the U.K. type sites including the Dimlington type area with which they are formally equated (Rose 1985). Therefore correlations can only be assumed. Gale et al. (1988) have considered one locality which has allowed for the first time a biostratigraphical analysis of deposits associated with the Hunstanton Till.

West and Whiteman (1986, page 57) argue that the assigning of formal stage names to local deposits is not good practice since lateral correlations to type sites are usually inferred. The authors agree with this; what follows, however, is a synthesis of the work of others who have attempted to place an age on the Hunstanton glaciation.

### HISTORICAL CONTEXT

The Hunstanton Till unit has long been recognised by many authors as being the equivalent of the Hessle unit in Lincolnshire. This was first proposed by Woodward (1884) and subsequently by Jukes-Browne (1887), Whitaker and Jukes-Browne (1899), Solomon (1932), Raistrick (1934), Suggate and West (1959), and Baden-Powell and West (1960). Solomon (1932) based his correlation on the erratic content and heavy mineral assemblage. Whitaker and Jukes-Browne (1899) suggested a correlation to the Hessle on the basis of the geographically-topographically similar positions the two tills occupy. As noted elsewhere in this paper the Hessle is now re-interpreted as the weathered zone of underlying tills (Madgett and Catt 1978), but nevertheless the basis of the correlation with the Skipsea Till remains.

## GEOMORPHOLOGICAL CONTEXT

The opinion has been given (Suggate and West 1959) that the freshness of forms such as hummocks (kames?) and minor closed hollows (kettle holes?) in Holkham Park (TF 883430) and the linear ridge (esker?) in Hunstanton Park (TF 696404) could not have survived landform modification during a full interglacial and glacial. Indeed Jukes-Browne (1887), when describing the Hessle of Lincolnshire, had proposed that the geomorphological features were formed by the original deposition. Straw (1960) claims that 'The ridge of brown boulder-clay at Heacham has a similar form to the ridge of "Hessle" boulder-clay at Stickney, north of Boston' (page 386) and suggests a correlation on these grounds.

## EARLY OR LATE DEVENSIAN?

Penny et al. (1969) published two radiocarbon dates of 18,240 ± 250 B.P. obtained from moss in freshwater silts found immediately below the Skipsea Till, in a small basin in the surface of the Basement Till at Dimlington in East Yorkshire. From this it was concluded that the maximum ice extent of the glaciation post-dated the Dimlington deposits.

At Roos Bog on the Withernsea Till surface, a further radiometric date of 13,045 ± 270 B.P. has been obtained (Beckett 1977) therefore allowing the conclusion to be drawn that the ice advance occurred between these dates; a period of approximately 5,000 years. At Kildale, west of Whitby, deposits within a kettle hole have yielded a moss flora from which a date of 16,713 ± 340 B.P. has been obtained (Jones 1977, and Keen et al. 1984). From the Kildale evidence the ice advance depositing the Skipsea and Withernsea Tills lasted less than 2,000 years.

Derbyshire et al. (1984) consider the Basement Till to be Devensian on sedimentological grounds and further proposes that it was this advance that reached the north Norfolk coast and deposited the Hunstanton Till.

Bowen et al. (1986) noted that the Devensian glaciation 'occurred sometime after about 26 ka B.P.' and 'reached a maximum extent around 18 - 17 ka B.P. and wasted from most of England,..........by about 14.5 ka B.P.' (page 310). Radiocarbon dates show the proglacial lake deposits of Lake Humber have a maximum age of 21,835 ± 1,600 B.P. (Gaunt 1981). The damming of this lake, and therefore presumably the damming of the Wash Gap, took place after this time.

Straw (1979a, page 22) notes the Hunstanton Till to be 'widely accepted as Devensian' in age. He suggests (1979b, pages 21 and 22) that two Devensian stadials can be recognised in eastern England, with the Hunstanton advance to be the earlier of the two. He also suggests (Straw 1979b, page 23), that the Hunstanton Till is 'directly correlative with the Lower Marsh drifts in east Lincolnshire' (Straw 1979b, page 23), the advance being late Early Devensian. He further states that the glaciofluvial landforms in north Norfolk suggest a stagnating ice front, which is in accord with the ice-surge model of Boulton et al. (1977). Straw suggests that the radiocarbon dates for the silts below the Holderness coastal tills were formed after the Early Devensian glacial episode and were overriden by a Late Devensian re-advance. Straw therefore believes in two glaciations; an early advance as far south as Norfolk, and a Late Devensian re-advance. Straw's conclusion draws heavily on geomorphological observations made in Lincolnshire and Yorkshire. Straw (1979a) considers an age older than 45,000 years B.P. to be likely for the Hunstanton glacial event.

Straw (1979) describes a palaeosol at Docking Common (TF 790357) incorporating an ice wedge cast and underlying an horizon containing humic material dated at 19,300 ± 300 B.P. and 24,000 ± 550 B.P. Based on geomorphic evidence Straw assigns an early Devensian age to the palaeosol, suggesting an age considerably older than the radiometric dates provided. He correlates the Docking Gravels, which underlie the palaeosol, with the Hunstanton glacial episode which he dates as early Devensian (earlier than 45,000 years B.P. - Straw 1979, page 314). The involutions in the gravels therefore point to a cold episode subsequent to these.

In a review of the stratigraphical evidence for the last glacial episode in Britain, Rose (1985) suggests that the coastal area of Dimlington in East Yorkshire should provide the type region for the Late Devensian Substage, which is defined (Shotton 1977) as being between 26,000 and 13,000 radiocarbon years B.P. and recommended that this episode should be termed the Dimlington Stadial. A stadial is defined as 'a subdivision of a glacial characterised by a relative deterioration of climate' (Rose 1989, page 47). Rose (page 51) considers that the Hunstanton facies was deposited during the Dimlington Stadial.

The Dimlington Stadial is effectively based on lithostratigraphy with bioistratigraphy playing only a supporting role. The sequences in north Norfolk have at present been correlated to the Dimlington entirely on the basis of lithostratigraphy.

## CORRELATIONS WITH DEPOSITS IN THE FENLAND REGION

Gallois (1978) tentatively correlates the Hunstanton Till with the tills of Lincolnshire and the March 'brickearth'. The latter deposit overlies the March Gravels which are interpreted as Ipswichian (West 1987). Gallois (1979) also tentatively correlates the Hunstanton deposits with some 'Fen-edge gravels' including Terrace 1 of the rivers Great Ouse and Cam, plus the Wretton Terrace of the River Wissey (page 31). Gallois provides no evidence as to the basis of these correlations.

## OVERVIEW

The bulk of opinion points to a Devensian age for the Hunstanton Till supporting the proposal of Catt and Penny (1966) and Madgett and Catt (1978). If $^{14}C$ dates obtained are a further guide then ice was starting to waste from north west Norfolk before 16,000 years ago (Jones 1977). Litho-stratigraphic correlations with sequences in Yorkshire and

Lincolnshire point to a Late Devensian age, however, the presence of datable material below the Hunstanton Till in north west Norfolk would clarify the issue.

Boulton et al. (1984) considered whether the Hunstanton advance features and deposits are a similar age to other deposits in north Norfolk. Boulton considers a possible Wolstonian age for the Hunstanton Till (but provides no clear evidence for his thoughts) whereas Cox and Thornton, in the same paper, hold to a Devensian age.

## LANDFORMS AND GLACIOGENIC DEPOSITS ASSOCIATED WITH THE HUNSTANTON TILL

### THE HUNSTANTON ESKER

The esker in Old Hunstanton Park (TF 6940), first noted by Whitaker (1883) as a glaciofluvial depositional feature, is considered by virtually all authors to be contemporaneous with the Till on the basis of its close proximity to, and inclusions of, Hunstanton Till.

Evans (1976) describes the esker in some detail. The approximately north south striking ridge is situated in a shallow valley which drains northwards to the sea having started further east in the area of Ringstead Common (TF 7240). The single ridge is sinuous with a length of approximately 2km consisting of sand and gravel and is independent of the underlying topography. At the only exposure where the internal structure and sediment could be analysed (TF 697405, sadly now ploughed over) Evans considers the sand and gravel to be of a predominantly local origin (maximum 81%) in an overall fining upwards cycle capped by flow till. Coarse grained gravels are at the base such as could be deposited by high energy torrential rivers. Evans considers the fining upwards sequence represents the waning of fluvial deposition and the flow till capping the sequence indicative of melt out from ice either adjacent to or above the esker.

Evans also describes normal faulting parallel to the esker flanks with synformal and antiformal folding occurring as a result of basal ice melt out. He considers therefore, that the sediments were deposited either englacially or supraglacially.

Evans, on the basis of his observed sedimentological and structural evidence, concluded an initial englacial origin for the esker which later developed as a supraglacial channel flanked by debris-rich ice, which upon melt-out, flowed towards and across the esker.

Evans concludes that the generally flat topped profile of the esker is the result of the slow melt of the underlying ice. A beaded profile is also seen in one part and may represent retreat stages of the glacier margin.

## RINGSTEAD DOWNS MELTWATER CHANNEL

Approximately 0.5 km to the south of Ringstead church (TF 707406) is the start of a steep sided, flat floored valley extending some 2km due west where it continues, less deeply incised, for a further 1.5km to the south west. At this point, 0.5km north of Manor Farm (TF 678387), the channel terminates.

Bonney (1915) and Baden-Powell and Reid Moir (1944) visited the Ringstead Downs and concluded that it was a dry valley, initiated by subaerial fluvial erosion.

Straw (1960) considered the Ringstead Downs to have formed as a result of an ice damned lake (east of Ringstead) overflowing along the southern edge of an ice lobe that advance into the valley of Old Hunstanton Park. The esker is situated in this valley and terminates just north of the meltwater drainage channel although it is likely that the meltwater from the esker continued into the channel. Straw's evidence for the ice damned lake is based on the presence of gravels east of Ringstead 'derived in large part from the surrounding slopes' (page 381).

## LANDFORMS AT HOLKHAM

Straw (1960) considered that the present day lake in Holkham Park (TF 883430) could be the site of a former meltwater channel for water from the Burn Valley. The valley between Warham All Saints (TF 945416) and Stiffkey (TF 973431) could also result from natural river and glacial meltwater drainage diversion caused by an ice dam.

## LANDFORMS AT HEACHAM

East of the village of Heacham a valley (the Sedgeford Valley) is partly infilled with sands and gravels in a series of isolated kames. The sediments of these landforms were considered to be contemporaneous with the chalky till by Straw (1960, Fig 1, page 381); whereas Evans (1976) considered them to have been formed during the 'Hunstanton Glaciation' based on the presence of erratics similar to those of the Hunstanton esker and of the close proximity to Hunstanton Till.

Evans describes the kames of the Sedgeford Valley in some detail. He considered that the gravels could be traced 8km eastwards into the Docking area. Detailed mapping needs to be undertaken to see how the gravels of Heacham relate to the Docking Gravels described by Straw (1979).

Evans considers the gravels to represent deglacierization and ice stagnation with the bulk of deposition taking place below the 30m contour. One of the kames, an elongate mound banked against the north side of a small valley (TF 699371) is exposed on its southern side. Material ranges from silty sand to boulders. Generally the coarser material is confined to the central section and is considered to represent an abandoned sediment choked englacial tunnel. Evans considers that the well stratified finer material may have been formed in a ponded area on the ice surface; the lack of channels and current bedding suggests a low energy regime. Fining upwards cycles may represent seasonal fluctuations. Melt-out of the underlying ice caused the lowering of the beds onto the valley floor and underlying tunnel deposits. Evans further considered that the present deposits are relicts of a much larger expanse dissected by the release of ponded water.

A red brown sediment is seen capping the sequence which may represent a flow till. At the time of observation (March 1990) it is likely that the excavation is to be re-opened.

### GAS-WORKS SITE: HUNSTANTON (TF 672403)

A former pit in Hunstanton (TF 672403), at a pre-existing surface height of between 6m and 15m O.D. (although Gallois (1978) considers a maximum height of 8m O.D.), has been referred to in a number of papers, Whitaker (1883), Whitaker and Jukes-Browne (1899), Woodward (1883), Reid Moir (1931). Reid Moir obtained implements from it (see Archaeology Section). A skeleton was also found (Newton (1898), Trueman Tucker (1898)). (Also see Archaeology Section).

The pit showed a 9.1m thickness of sands and gravel (some pebbles being very rounded -'cannon-shot'- with some clasts greater than 0.3m in diameter) which overlay chalk rubble and carstone. Cross stratification was apparent in some horizons. Seeley (1866) noted that erratic material was abundant to such an extent that the deposit should not be called a flint gravel, although Lamplugh in Whitaker and Jukes-Browne (1899) indicated flint was by far the commonest. Of interest is Seeley's note (1866) - and again by Lamplugh - of the presence of armoured clay balls.

A number of marine mollusca (see Table 1), have been obtained from the deposit which were apparently in a condition to be considered not reworked.

GASTROPODA
*Buccinum undatum*
*Dentalium entalis*
*Littoria littorea*
*Murex erinaceus*
*Nassa reticosa*
*Nassa reticulata*
*Natica*
*Purpura lapillus*
*Turritella communis*
*Artemis lincta*

BIVALVIA
*(Cardium edule) Cerastoderma edule*
*Corbula gibba*
*(Cyprina islandica) Arctica islandica*
*Donax vittatus*
*Mactra ovalis (Mactra elliptica)*
*Mytilus edulis*
*Nucula nucleus*
*Ostrea edulis*
*Scrobicularia piperata*
*Tapes pullastra*
*Tellina balthica*
*Fusus antiquus*
*Tellina obliqua*
*Mya truncata*
*Corbula nucleus*

TABLE 1:
(Compiled from Seeley (1866) and Whitaker and Jukes-Browne (1899)).

The genera are found in the North Sea today therefore indicating a marine and non-glacial environment of deposition for the gravels.

Seeley (1866) notes that the 'shells occur in several distinct bands of gravel, and at various heights, but are most numerous and best preserved in the coarse layers'.

It is interesting that Geikie and Jukes-Browne (Trueman Tucker 1898) suggest 'that several distinct periods are represented' (page 7) quite what in stratigraphical terms is meant by this is unclear; Geikie - working from photographs [!] - also considered a glaciofluvial origin.

Correlations have been made with the March and Whittlesey gravels and the deposits dated as post-glacial by Whitaker and Jukes-Browne (1899). Although Lamplugh in the memoir, because of the inclusions of possible till in the gravel, concludes it is of Last Glacial age.

Jackson (1910) examined the quarry and considered it to be 'extremely false bedded' with 'lenticular masses of fine quartzose sand, chalk grit, and small, worn grains of lignite, and bituminous shale.' (page 31). Erratics of granite, syenite, porphyrite, basalt, gneiss and schist are 'very numerous' (page 31). Jackson, observed 'Brown Boulder Clay...... irregularly mixed up with the sand and gravel' (page 31). If this 'brown boulder clay' is the Hunstanton Till then clearly part or all of the sand and gravel sequence is either Devensian or Holocene. Such a conclusion must be treated with some scepticism considering the findings of Gallois (1978) where 2km. to the north (TF 681425) of the gas-works site, Hunstanton Till clearly overlies a sediment, described below, which he considers to be the correlative of the gas-works Gravel. This would then date the gas-works Gravel as Early Devensian or pre-Devensian.

## OLD HUNSTANTON RAISED BEACH

Gallois (1978) notes a former beach deposit banked up against a cliff of Carstone, Red Chalk and Chalk and underlying the Till at Old Hunstanton. Excavations (at TF681425) displayed basal shingle and chalk scree overlain by a 'crudely imbricated coarse chalk gravel with lenses of flint shingle' (page 21), in turn overlain by a cryoturbated chalk gravel. The shingle, chalk scree and imbricated chalk gravel, were interpreted as raised beach deposits. Gallois correlates the sequence with the gas-works site and concludes that the deposits were formed with 'a climate and sea level similar to that of today' (page 22).

Jukes-Browne (1885) describes the Hessle Till in the Holderness peninsula to be overlying beach deposits and chalk cliffs; a situation comparable to those at Hunstanton. Lamplugh (1888) describes at Sewerby, Yorkshire (TA 199686) a gravel lithology and Molluscan assemblage similar to Hunstanton's. A vertebrate assemblage has also been described from Sewerby considered to be indicative of a warm interglacial ( Boylan 1967, and Catt and Penny 1966).

## TOTTENHILL GRAVELS

Gallois (1978) describes the Tottenhill gravels exposed south of King's Lynn. Heights of these deposits range from +3.7m O.D. to +7.6m O.D. At the Tottenhill Gravel Pit (TF 632116) two units were recognised. The lower a cross-bedded, medium to coarse, poorly sorted gravel. The upper unit is unconformable with the lower and is composed of fine to medium gravels displaying a higher degree of sorting and planar cross bedding. Gallois interprets a cryoturbated deposit overlying the gravels as possibly the Hunstanton Till. Straw (1979a) considers an Early Devensian age likely for the Upper Tottenhill Gravel.

## ERRATICS

Jackson (1910) notes a number of large erratics that can be seen in west Norfolk. It is likely that these are linked to the Hunstanton glaciation but a previous history should not be ruled out. A basalt erratic can be observed on Heacham Green (TF 681379).

## PERIGLACIAL FEATURES

Evans (1976) cites many examples of periglacial features within the west Norfolk area including ice wedge casts, polygonal and striped patterns, involutions and pingo ramparts (TF 7316).

## PALAEOSOLS

A succession at Heacham (TF 683387), as described by Evans (1976), shows a palaeosol between chalk muds and rubbles with structures indicating cold conditions. The palaeosol is sandy, leached, thin and not laterally extensive. A Molluscan holoarctic fauna was extracted. Evans tentatively correlates the sediments above the palaeosol with Younger Dryas and the palaeosol with the Windermere Interstadial. This sequence requires further detailed investigation.

A palaeosol described by Straw (1979) at Docking Common has been noted earlier.

## ARCHAEOLOGICAL INFORMATION

Reid Moir wrote a number of papers detailing claimed artifacts from the Hunstanton Till (Reid Moir 1930, 1931). A number of these 'flint implements' have recently been re-examined in the British Museum by John Wymer (1990, pers. comm.) none of which are particularly diagnostic of any one period. Three blades in the collection are probably Mesolithic. Moir refers to the 'implements' as having striations (Moir and Burchell 1930) for which Wymer could find no evidence. Wymer further considers that the flakes are either not in-situ or were intrusive. Wymer (1986) notes that many of Reid-Moir's 'allegedly worked flints ....... are blatantly the result of natural agencies' (page 10).

Reid Moir (Baden-Powell and Reid Moir 1944) describes a flint core found at Happisburgh in supposed Hunstanton Till age deposits and dates it as Upper Palaeolithic but was unable to be more specific. As noted elsewhere in this paper, doubt is cast on the deposit at Happisburgh as being of Hunstanton facies. The core was found only 0.3m from the surface, considered by Reid Moir to have been in undisturbed material. It is, however, considered more likely by Wymer (1990, pers. comm.) to have been intrusive.

Newton (1898) and Reid Moir (1931) described a skeleton found in September 1897, in situ 2m below the surface in the gravel pit at Hunstanton (TF 672403), in the gas-works Gravel described earlier. Trueman Tucker, the finder, sought the help of Dr Hutchinson to detail the find (Trueman Tucker 1898). The frontal portions of a skull and face bones embedded face down in the gravel, were accompanied by a portion of the left clavicle, the lower part of the left humerus, the first phalanges of the hand, portions of the left scapula, and considerable portions of both femora. Sixteen teeth were also recovered with the lower incisors showing great wear. Hutchinson considered the bones to be below average size with characteristics of recent forms. A significant portion of the skeleton was missing. Sir Arthur Keith (1913) also undertook a detailed analysis of the skeleton and concluded that the fragments were of a woman of slender build and approximately 1600mm in stature. The age of the woman (between 35 and 45) was estimated by examination of the cranial suture. Keith noted that only eight teeth were present (not the sixteen noted by Trueman Tucker 1898) but that they are not worn to an extent expected in a woman of this age. Keith considered the skeleton to be early Neolithic (possibly even earlier) based on their brittle and non-mineral impregnated condition. He also notes, however, that the skull type may indicate a possible late Palaeolithic date. Trueman Tucker places some considerable emphasis on the bones being retrieved from undisturbed sediment, i.e. they are not burial remains. He cites a continous layer of sediment in position above the site of the skeleton. Such skeletal material must be treated with some caution, however, as burials can occasionally leave little trace within the sediment. Trueman Tucker was also of the opinion that the large number of 'delicate shells' noted as being present in the same strata, indicate that little alteration via acidic percolation took place following burial. Dr Hutchinson removed the bones to his museum in Haslemere, Surrey, from where they were transferred to Ipswich Museum in 1931.

Human bones were also recovered from the same pit in 1862 and Trueman Tucker considers they might belong to the same skeleton. Unfortunately details of the stratigraphy of the beds from which these particular bones were recovered do not exist and therefore their value is minimal. There present location also remains a mystery.

Wymer (1985) describes Palaeolithic hand axes from the Tottenhill Gravel at Tottenhill (TF 635115) and hand axes of the Acheulian Industry found in gravels at South Wootton (TF 642224). These gravels at South Wootton are probably to be equated with the Tottenhill Gravels. Wymer notes such hand axes are not known before the Devensian, therefore suggesting a possible age for the Tottenhill gravels.

## TOPICS FOR FUTURE INVESTIGATION

A number of topics are identified as requiring further investigation:-

1. Straw (1979b) strongly supported the existence of a Lake Fenland (Ouse Lake of Raistrick (1934)) of maximum level 30m O.D. which was formed when ice closed the Wash gap. Lake overflow could have been via the Waveney Valley (page 30). More work is needed to establish primarily the existence of the feature, and

the nature and history of this potentially important and presumably extensive feature.

2. The Hunstanton Gravels were noted at the pit just north-west of the gas-works site (TF 672403) and at the north end of the Cliffs (TF 681425) referred to by Gallois (1978) as the 'Hunstanton Raised Beach' (page 6). The former locality, however, is now used as a caravan site and the old faces are grassed over. A temporary or permanent section would be invaluable for further study. The origin and extent of these gravels within north west Norfolk should also be investigated.

3. The extension of the 'Hunstanton' ice sheet south of Ken Hill, Snettisham (TF6734) seems very likely in view of the ice contact features at Dersingham and the Till located in the southern Wash, and detailed mapping needs to be undertaken in this area. Construction of the Dersingham - Ingoldisthorpe - Snettisham by-pass began in December 1989. Boreholes indicate sands with traces of gravels overlying peats in a number of locations (e.g. TF 679304, TF 679306, TF 680308, TF 681309). Elsewhere possible fluvial (? glaciofluvial) sands and gravels (e.g. TF 675334, TF 677335, TF 677337), and clays (e.g. TF 677338, TF 678340) can be seen.

4. A detailed sedimentological analysis covering the total extent of the Hunstanton Till has yet to be published. A full analysis of the varying facies must be undertaken, as should a re-mapping of the Till and its associated deposits and features, in order to establish a more reliable ice front maximum position. This paper has pointed out a number of differences to Straw's (1960) widely accepted map.

5. Finding deposits that would allow chronostratigraphic and/

or biostratigraphic dating would help to support the lithostratigraphic correlations made with deposits north of the Wash.

6. We believe that the establishment of a type section with SSSI status would prove invaluable for future research. To this end we strongly encourage the Nature Conservancy Council (now English Nature) to develop part of the Holkham Brick pit (TF 863428).

## ACKNOWLEDGEMENTS

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The illustration on the front cover is taken from Figure 286 of Lyell's "Elements of Geology", 1865 (6th Edition), and shows columns of potstones in the Late Campanian Chalk of a quarry on the River Bure near Horstead, Norfolk. The upper part of the section consists of Crag gravels resting on an erosion surface which truncates the potstone columns.

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